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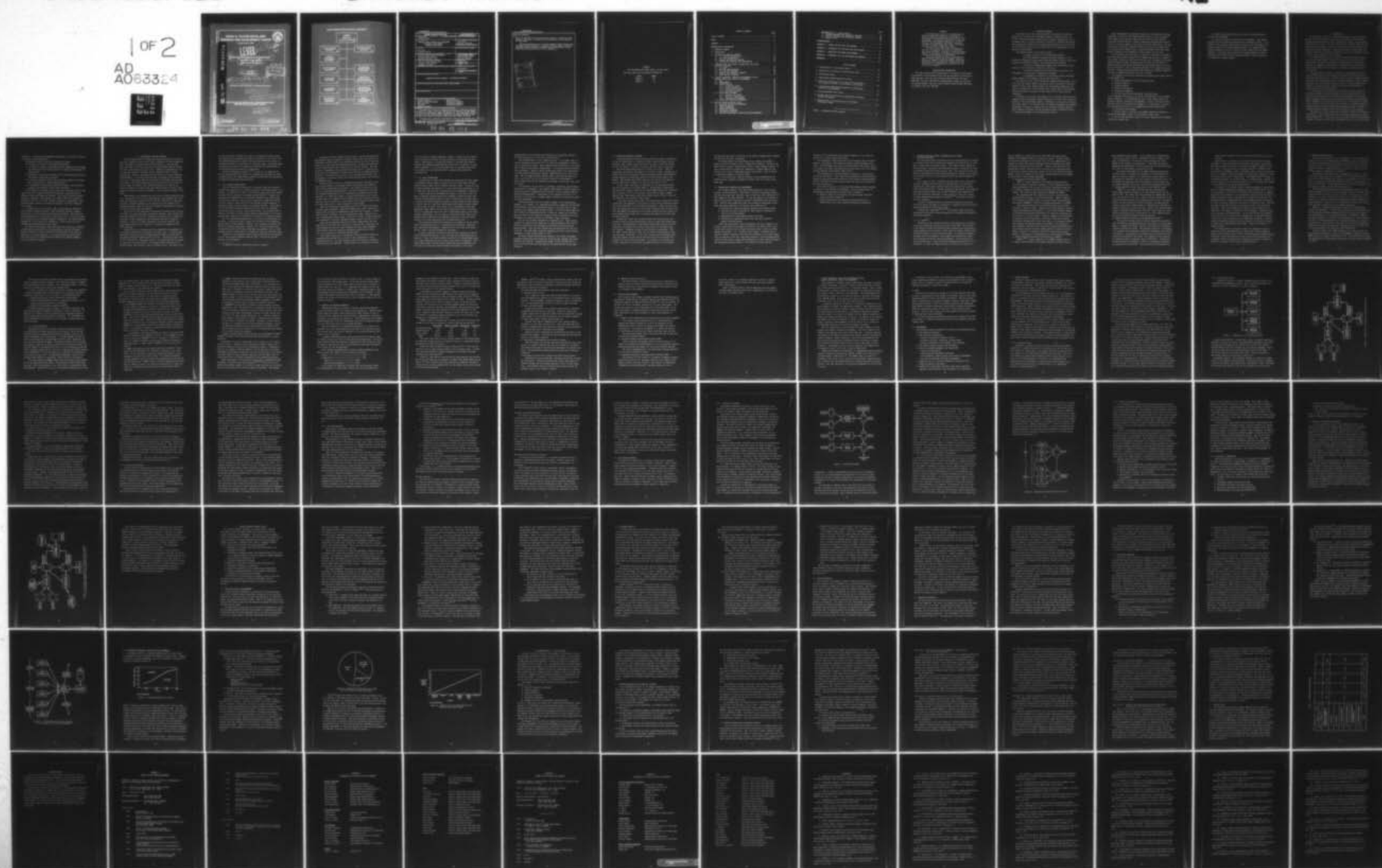

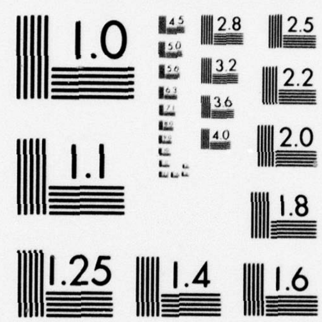

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COMPUTER SCIENCE RESEARCH AND DEVELOPMENT IN SUPPORT OF SHIP DESIGN, PRODUCTION AND REPAIR.

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by

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(9) Final rept. Feb 77- Sep 78,

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(17) SF53532020

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COMPUTATION, MATHEMATICS AND LOGISTICS DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

(12) 101p.

COMPUTER SCIENCE RESEARCH AND DEVELOPMENT IN SUPPORT OF SHIP DESIGN, PRODUCTION AND REPAIR

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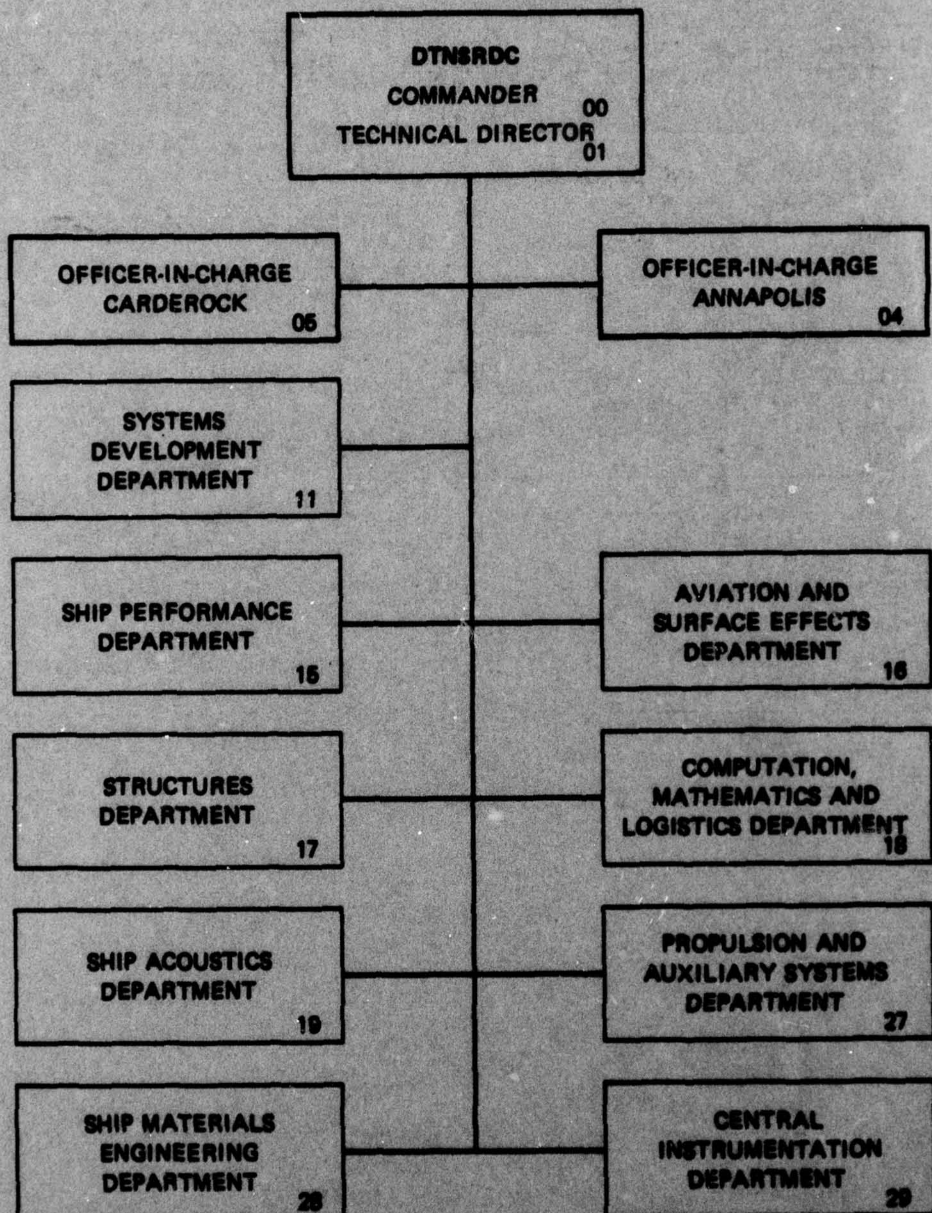

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DTNSRDC-78/104	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) COMPUTER SCIENCE RESEARCH AND DEVELOPMENT IN SUPPORT OF SHIP DESIGN, PRODUCTION AND REPAIR		5. TYPE OF REPORT & PERIOD COVERED Final Report Feb 1977 - Sep 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ruey Chen Elizabeth Cuthill		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship Research and Development Center Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 62721N Task Area NR001-007 Work Unit 1805-001
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research (437) 800 North Quincy Street Arlington, VA 22217		12. REPORT DATE December 1978
		13. NUMBER OF PAGES 97
14. MONITORING AGENCY NAME & ADDRESS(if different from Contr ing Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Science
Computer Aided Ship Design
Ship Production
Data Base
Computer Graphics
Design Automation
Production Automation
Distributed Computing
Software Development

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The efficiency of the U.S. shipbuilding industry is especially important to the Navy in terms of military readiness and the amount of the Navy budget for Navy ship construction, repair and alteration. The shipbuilding industry is one of the most labor-intensive industries. Continual increases in shipbuilding costs reduce the number of ships the Navy's budget can afford.

In recent years, industrial productivity in the U.S. has improved very → next page

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This study determines that a five-year computer science research and development program in support of computer aided ship design, production, and repair can be economically justified and that productivity of ship design and production in the U.S. will be improved.

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PREFACE

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ABSTRACT

The efficiency of the U. S. shipbuilding industry is especially important to the Navy in terms of military readiness and the amount of the Navy budget for Navy ship construction, repair and alteration. The shipbuilding industry is one of the most labor-intensive industries. Continual increases in shipbuilding costs reduce the number of ships the Navy's budget can afford.

In recent years, industrial productivity in the U.S. has improved very slowly in comparison with other industrial countries. Productivity gain depends on the degree of automation and mechanization and the potential for improvement.

This study determines that a five-year computer science research and development program in support of computer aided ship design, production, and repair can be economically justified and that productivity of ship design and production in the U.S. will be improved.

ADMINISTRATIVE INFORMATION

The work reported here was performed at the David W. Taylor Naval Ship Research and Development Center and was supported by the Office of Naval Research, Code 437, under Program Element 62721N, Task Area NR001-007, Work Unit 1805-001 with supplementary support by the Naval Sea Systems Command, Code 03F, under Program Element 62760N, Task Area SF 53532020, Work Unit 1808-009.

1. EXECUTIVE SUMMARY

The objectives of this study have been to determine the potential benefits of a research and development program in computer science to the U.S. Naval ship design, construction, and repair communities; and to recommend, where it can be economically justified, a research and development program that could result in significant reductions in cost and time for ship design, production, and repair and also in improvements in ship quality and performance.

The approach taken in this study has been

to conduct a survey of the shipbuilding industry

to review computer technology presently employed in ship design and construction and related system development efforts, along with economic and technical benefits, both achieved and anticipated

to project a computing environment that would substantially enhance future ship design, production, and repair

to identify computer science areas requiring research and development to achieve such a computing environment

to recommend an economically justifiable research and development program in the computer science areas identified.

The content of this report follows the approach outlined above. As a first step this report seeks to provide an overall perspective from which computer science areas needing support for ship design, production, and repair are identified. This study has been a joint effort with Professor Richard Riesenfeld, University of Utah, whose work is being reported separately.

According to our study, ship design is still largely a manual process. Computer science technology in general appears not to have been adequately applied by the shipbuilding industry. Hindrances to wider use of computer technology appear to be the high costs of software development and hardware procurement, the lack of incentive for the capital investment needed to apply computer technology, and the relatively modest coordinated efforts in software development in the shipbuilding industry.

Major improvements in precontract design can be accomplished through integrated, interactive ship design systems, which will tie all applications together for sharing a common data base and for using computer controlled drafting devices to produce engineering drawings.The trade-off study is a crucial element in the pre-contract ship design stage, and such a system will allow more trade-off studies to be done in a shorter time. In the post-contract design stage, a large percentage of the ship design detail processes can be automated to reduce design cost and time.

Our conclusions are that there is a need for a research, development, and technology transfer program in the computer science area in support of ship design, production, and repair, and that such a program can have high payoff in making software development more reliable and economical, in making computer-aided design and manufacturing systems easier to use and more cost-effective, and in automating much more of the production process. The Navy's Computer-Aided Ship Design and Construction (CASDAC) community would be an immediate beneficiary of such a program.

The computer science areas identified as requiring additional research and development are

- design and management of very large data bases
- computer graphics
- design automation
- production automation
- distributed computing
- software acquisition, development, and maintenance

It is recognized that these are all active research areas in the computer science community. The recommendation here is that ongoing work be influenced, adapted, developed, and augmented, so that it will more nearly meet the needs of the shipbuilding community. In particular, in each of the research areas cited, it is recommended that the program should

- characterize requirements
- review, exploit, influence, and augment ongoing and planned research and development efforts in the computer science area
- put the most promising results of current research and development efforts into usable form

- identify and support high pay off areas including additional research and development.

A five-year program totalling $7.4M is recommended. This amount includes $1.4M for program coordination and technology transfer. A key element in the suggested organizational structure for the program is an advisory panel which includes representatives of the CASDAC and shipbuilding community and of the computer science research and development community. This panel would work with the program manager in identifying and prioritizing needs, evaluating proposals, and reviewing and critiquing the proposed program.

2. INTRODUCTION

The efficiency of the U.S. shipbuilding industry is of great importance to the Navy in terms of both military readiness and the portion of the Navy budget designated for ship construction, repair, and alteration ($8.5 billion in FY 78). For more than 20 years, most Navy ships have been built by private shipyards, and since 1968 all Navy ship orders have been placed with private shipyards. Improving efficiency of ship design, construction, and repair operations in both private and Navy shipyards should result in direct savings to the government.

The shipbuilding industry is one of the most labor-intensive industries in the United States. Continual increases in labor and material costs reduce the number of ships that the Navy budget can afford. In addition, the number of skilled workers available for ship construction has declined, making it more difficult to maintain the quality of ship construction.

The application of computer technology to shipbuilding presents an area with high potential for improving efficiency and reducing costs in ship design and construction. An early application which gained worldwide recognition was the Norwegian Autokon System, introduced in 1963. Autokon addressed steel cutting under numerical control. Other applications of computers to shipbuilding are being used and developed principally in Europe, Japan, and the United States.

In the United States, progress has been slow and little money has been made available to advance computer technology and applications in this very promising area of ship design and construction. As a result, ONR has supported the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) and the University of Utah for a joint one-year research study. These two activities have worked together to determine whether an expanded computer science research and development program in support of computer-aided ship design, construction and repair can be justified.

The objectives of this study are to determine potential contributions and benefits to the communities involved in design, construction, repair, and procurement of U.S. Navy ships from a directed research and development program in computer science; and to recommend, where it can be economically

justified, a research and development program that will result in products to be used in those communities.

The approach taken to meet these objectives has been

- To conduct a survey of the shipbuilding industry
- To review the computer technology presently employed in ship design and construction and related projects in computer aided design and manufacturing
- To project a computing environment that would substantially enhance ship design, production, and repair
- To identify computer science areas requiring research and development to achieve such a computing environment
- To recommend an economically justifiable research and development program in the computer science areas identified.

At the outset of the study, it was clear that a thorough review of the state-of-the-art in computer-aided ship design and construction and in computer science technology was required. This review included extensive literature searches on both domestic and foreign practices and visits to shipyards in the U.S. and other countries advanced in shipbuilding. More than 300 papers, reports, and books were studied, and several shipyards were visited.

In connection with this project, ONR is sponsoring two workshops to which technical experts from Navy, other government agencies, academic institutions, and the shipbuilding industry are invited. The first workshop (Appendixes A and B) was held on June 29-30, 1977, to review the scope of this project and to exchange technical information. The second workshop (Appendixes C and D) was held on November 21, 1978 to review the final findings and recommendations of this study.

The present Navy Computer Aided Ship Design and Construction (CASDAC) program supports preliminary and contract design, which are performed primarily in-house, as well as detail design and construction, which are carried out in private shipyards. It is anticipated that the proposed effort will result in products directly usable by the CASDAC community and the shipbuilding industry.

3. SHIPBUILDING INDUSTRY OVERVIEW

The 1973 Middle East oil embargo and ensuing increases in oil prices have had a cumulative effect on the world economy and on world shipping as well. The impact on shipbuilding has been universal. Many merchant ships have been forced into layup, and new shipbuilding contracts during the past several years have been scarce. Commercial shipbuilding in the U.S. has been similarly affected, and the backlog of work is rapidly diminishing. Many U.S. shipyards need new contracts to sustain workload and employment. It has been predicted that the capability and workforce of the U.S. shipbuilding industry will become increasingly idle from next year onward. The shipbuilding mobilization and resource base could thus be appreciably diminished, with lasting consequences in terms of the nation's capability to produce and repair Naval vessels in times of emergency and to produce vessels of commerce to serve national security at all times.

Shipbuilding is an assembly-type and a labor intensive industry; about 40 to 50 percent of the cost (including material and equipment) of a merchant ship and about 30 percent of the cost of a Naval ship is labor and overhead. Although economies can be achieved by series production of standardized ships, under even the most favorable circumstances, shipbuilding is not a mass production industry.

While the U.S. has experienced rapid domestic inflation over the past few years, the problem has been even greater overseas. Many foreign countries have reduced or lost their competitive positions due to exceptional increases in labor compensation and sustained high rates of domestic inflation. As the U.S. reaches wage-parity with other countries, the shipbuilding industry can be expected to become more competitive with these countries.

Productivity as it concerns facilities, manpower, and management is a key factor in the ability of shipyards to reduce costs. In recent years, industrial productivity has been improving more rapidly in Japan and in many Western European countries than in the U.S. According to data (1967 to 1977) from the U.S Department of Labor, the average productivity gains in Japan are 6.8 percent yearly, in the Common Market countries 5 to 6 percent yearly, and in the U.S. only 2.3 percent yearly. The point is not

so much that wages increased, but that the consequent gap between gains in productivity and compensation produced an increase in unit labor costs. The shipbuilding market, so highly labor-intensive even at its best, is especially sensitive to differences in unit labor costs. Continuing gains in productivity depend on the degree of automation and mechanization in each shipyard and the potential for improvement.

Several investigatory studies,[1,2,3*] reports of the Commission on American Shipbuilding,[4] and reports of Congressional hearings[5] are aimed at improving the U.S. shipbuilding industry's productivity and maintaining an adequate shipbuilding industrial base.

3.1 U.S. PRIVATE SHIPBUILDING

The U.S. shipbuilding industry is a relatively small but essential industry with respect to the economic, political, and defense needs of the country. It ranks 40th in order of size based on gross sales and accounts for less than 0.3 percent of the gross national product.[4] However, the importance of shipbuilding to the national interest is far greater than its size would indicate. The U.S. has relied on the oceans for security and still relies on them heavily for the movement of goods essential to national security, national growth, and national survival. Sixty-nine of 72 critical materials must be imported by ship.[4] The U.S. flag-fleet carries only about 5 percent of our foreign trade. Our post-World War II fleet of over 4800 U.S. flag merchant ships has diminished to 577 and the present fleet ranks tenth in the world in the size of its merchant marine.

The U.S. shipbuilding industry is not a factor in international competition. It does only about 4 percent of the world's total commercial shipbuilding and ranks seventh. However, U.S. shipyards are heavily committed to building large-volume, complex, and sophisticated Navy ships. As measured by total facilities, technology, and manpower, the U.S. shipbuilding industry easily ranks as a leader with Japan and the Soviet Union.

During 1977, four American yards received contracts for the construction of 16 new jack-up offshore drilling rigs.[6] No other country has matched this performance.

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*A complete listing of references is given on page 85.

In addition to Naval shipbuilding and repair, private shipyards build most merchant ships for domestic customers, either under the construction differential subsidy (CDS) of the Merchant Marine Act of 1970 or under the protection of the Jones Act (Merchant Marine Act of 1920) which specifies that all intercoastal traffic must move in U.S.-built vessels. The CDS is meant to compensate for the difference between the U.S. shipyard price and a fair and representative foreign yard price with a maximum subsidy of 50 percent. The distribution of work in the shipbuilding industry runs approximately 65 percent on Navy new construction and repair and 35 percent on commerical work.

Over 80 percent of the U.S. shipbuilding industry's workload is subject to the influence of government--Naval ship building and commercial ship building subsidized by government. The industry continues to rely heavily on government appropriations. The future direction of the whole U.S. shipbuilding industry will be determined by government actions and responses. It seems that without a coordinated national policy on shipbuilding--Naval and commercial--the downward trend will continue and will lead to a loss of capability in this country with consequent higher prices for ships produced by a reduced industrial resource base.

There are, according to government statistics,[4,5] some 50 principal privately owned companies, dispersed throughout the country, having the capacity for building or accommodating ships 400 feet or longer. Of this, some 18 private shipyards, in a very substantial sense, compose the nation's shipbuilding resource base. Data from U.S. Dept. of Labor show that total employment in private shipyards reached a high of 181,000 in 1977.

Some private shipyards specialize in Naval shipbuilding, and some engage only in merchant ship construction; some do both. Most major private shipyards are units of large corporate entities. Major shipyards also maintain extensive design and engineering capabilities; others rely on the services of independent design agents.

Ship repair constitutes a substantial volume of work for those U.S. shipyards which dedicate all or a part of their competence to this essential activity. For some shipyards, Naval ship repairs, overhauls, and alterations are important. Others depend on a continuity of repairs

to U.S. as well as foreign commercial vessels. Unlike new ship construction, the near-term outlook for ship repairing is predictable and more stable. Ship repair is a sustaining element in the maritime industry. Periodic and emergency maintenance and repair work is essential to keep vessels operable. A critical requirement for a successful repair yard is its ability to meet schedules and to complete work rapidly and satisfactorily.

3.2 U.S. NAVY SHIPBUILDING

Although the U.S. Navy has developed and constructed the most sophisticated Naval vessels afloat, the size of the U.S. Navy fleet has been declining from a peak of 976 in 1969 to 459 (May, 1978). It may soon drop to below 453 ships--the smallest U.S. fleet since before World War II. At the same time, the missions of the Navy have not diminished in importance.

A basic question of philosophy with respect to the role of the U.S. Navy in national strategy seems to have emerged: should the Navy's missions be directed mainly toward sea control--keeping the sea lanes open; or should the primary emphasis be placed on power projections--the ability to quickly deliver a task force and knockout punch against global targets at sea or land; or both? This contest of not necessarily conflicting approaches could, because of the type of ships and the size of the Navy fleet to be maintained and built, have a determining effect on the future of Naval shipbuilding. An early goal of restoring the Navy fleet to an optimum level of 600 ships will probably not be met in the next decade because of the continuing escalation of shipbuilding costs.

There have been conflicting estimates as to whether or not the Soviet Union is outbuilding the U.S. In assessing this situation, trends are more significant than numbers. However for the first time in 30 years, the U.S. faces a serious challenge on the oceans.

In order to maintain a degree of stability and continuity in the nation's shipbuilding industry, a firm five-year Navy shipbuilding plan is essential. Such a plan would provide incentive to the shipbuilding industry to plan ahead for the use of capital, facilities, and manpower. The latest (March 1978) five-year Naval shipbuilding plan contemplates construction of 70 new ships (reduced from 150 new ships in five years

proposed about a year earlier) and conversion of 13 existing vessels in the FY79-83 period, at a total cost of $32 billion.[7]

Navy shipbuilding is a very complex process. It is highly labor intensive requiring specialized skills in production management, in design, and in construction trades. Naval combatant ship construction is very much more intricate than merchant shipbuilding. It requires much more detailed work assignments. Moreover, Naval shipbuilding requires the installation of highly sophisticated weapon systems, communications, and control systems. The time span from ship contract award to delivery may take from four to six years,[8] for the process must include the development of detail design, material and equipment procurement, construction, test, and sea trials.

The complexity of the process of planning, scheduling, and building a Naval vessel is tremendous. For example, approximately 3,000 man-years are required to build a submarine while an aircraft carrier requires approximately 20,000 man-years.[5] During most of the construction cycle, it is practical to utilize only a limited number of workers on the ship by reason of space limitations.

The Navy has been by far the largest customer of the shipbuilding industry. As a result, U.S. shipyards have greater capability for building one-of-a-kind of the most sophisticated ships in the world than for mass producing less complex large merchant vessels. In FY78 the Navy budget was $5.8 billion for shipbuilding and $2.7 billion for repair and alteration. About one-third of the repair and alteration work is performed in private shipyards; the other two-thirds is performed in Naval shipyards.

The role of the Naval shipyards is an important one. Their primary function is overhauling and repairing our complex combatant ships and installing, maintaining, and checking the sophisticated electronics and weapon systems. They also have capabilities and facilities for ship construction. The eight Naval shipyards remaining open had a total civilian employment of about 65,000 workers in 1977.[5]

The Naval shipyard modernization program is the capital investment program through which major industrial facilities and equipment for Naval shipyards are acquired. Implementation began in FY70; through FY76, a total of $379.8 million has been approved for modernization of the eight shipyards.

3.3 FOREIGN SHIPBUILDING INDUSTRY

The world shipping recession deriving from the economic repercussions of the 1973 Middle East oil embargo has had a universal impact on shipbuilding. Many tankers have been forced into layup. The world already has all the ships it is likely to need for the next seven to ten years.

The world shipbuilding industry is really in a crisis. There is tremendous overcapacity, and demand for new ships is weak. Competition is keener than ever as shipyards in Western Europe and Japan find themselves bidding against such developing countries as South Korea, Brazil, and Taiwan. New merchant ship orders placed in 1977 totaled only around 11 million gross tons as against 73.6 million gross tons in 1973.[7]

In 1977 Japan, continuing its dominance in the shipbuilding field, received 52 percent of the world market.[7] Shipbuilding in South Korea has raised that country's share of the world shipbuilding orders from less than 2 percent in 1973 to 5.7 percent, second only to Japan. Norway ranked third. The Swedish yards, which ranked second in world order during 1972/1973, have fallen to fourth place.

In the past several years, some of the developing countries have established their own shipyards to build their national fleets themselves rather than having them built in the established shipyards. These countries are also very competitive because of their modern shipyards and low labor costs. This development has aggravated the existing problem of excess capacity in world shipbuilding and has led to increased government aid in major shipbuilding countries.

Insufficient orders and increased competition from emerging shipbuilding countries have spelled disaster for the traditional shipbuilding countries. The governments of most major shipbuilding countries and the industry itself within those countries now accept the inevitable need for cutbacks. Shipyards are getting aid from their governments. With big tanker orders wiped out Japan, the big tanker-building power during the boom years (1972/1973), is in direct conflict with the European shipyards for smaller and more specialized ships which had previously been regarded as their particular preserve. In response to the present situation, Japan also is cutting back on manhours worked in the shipyards.

The situation has also hit very hard at the smaller Japanese yards, several of which have gone into liquidation.

The recent number two shipbuilding nation, Sweden, has planned a drastic cut-back in capacity and is closing some shipyards. Virtually the whole of that country's shipbuilding industry, except Kockums shipyard, is now a state-controlled corporation, apparently to enable Sweden to exit from the front rank of shipbuilding slowly and smoothly. This situation is duplicated elsewhere in Western Europe.

It is predicted that a genuine recovery of world shipbuilding, dependent on the resurgence of demand for tankers, will be at least seven years away.

3.4 SHIPBUILDING PROBLEMS AND IMPROVEMENTS

The foremost problem in the shipbuilding industry is that of maintaining a stable workload.[4] Historically, a widely fluctuating workload has been the single most important cause of high costs and inefficiency for both commerical and Navy shipyards. As with any industry, the problem is that of utilizing the resources to produce a reasonable return on investment. However, most shipbuilders have the problem of maintaining an adequate and stable orderbook; fluctuations cause difficulty in

- Obtaining and retaining competent personnel and skilled workers
- Obtaining necessary financing for large capital investments in facilities and R&D programs
- Establishing and maintaining suitable facilities
- Maintaining an organization which will use these resources properly and efficiently

When past workload has varied considerably and future demand is uncertain, shipbuilders must attempt to maintain a low capital/labor ratio so that plant capacity can be raised or lowered rather quickly to reflect changes in workload. U.S. shipyards need a stable, continuing flow of orders for Naval or merchant ships with the opportunity for a profit before they can logically invest the large sums required to move the shipbuilding industry further from a largely labor-intensive to a more capital-intensive and technology-intensive industry. The beneficial effects and the

efficiency of the shipyards can be greatly enhanced if the orders are repetitive, to permit series production.

The complexity of Navy ships has been increasing to meet the Navy's mission. Furthermore, ship design and weapon system development span years. The development period of the weapon system itself varies from 6 to 12 years; the design and construction of the ship to carry the weapons systems typically takes another eight years.[8]

The complexity of ship design makes it difficult to foresee accurately the end product. Also, many new technologies are often developed during the long ship design and production and weapon system development period, resulting in frequent change orders that cause cost overruns in Navy ship acquisition.

Since over 80 percent of the private shipbuilding industry workload is subject to the influence of government, a firm national policy on maintaining an adequate marine industry base is needed to

- Maintain stability of production achieved through long order books and series production
- Improve productivity by increasing capital investment in modernization and in ship design and production automation.

4. COMPUTER-AIDED SHIP DESIGN, CONSTRUCTION, AND REPAIR ACTIVITIES OVERVIEW

The developing warfare technology and the corresponding threat imposed on our Naval forces has increased the complexity and sophistication of the Navy's combat ships and weapon systems. This sophistication impacts on the ship design, production, and maintenance process, increasing the time and manpower required and their overall costs. The complexity of the process has increased to the point where hand-analysis, design, and production are no longer efficient or even possible within the time and budget constraints.

For a number of years, computers have been used in the shipbuilding industry, although their use has, for the most part, been confined to replacing the slower manual methods previously employed with a higher speed calculating ability. However, during the past decade, large computer aided ship design systems, such as ISDS,[9] CAPDAC,[10] and shipyard MIS[11] have been initiated, developed, or used by the U.S. Navy, and a number of large computer-aided production systems[12,13,14] have been introduced into U.S. shipyards.

A survey of computer-aided ship design and production activities in Western Europe and Japan is contained in a separate report by Professor Richard Riesenfeld of University of Utah.

International symposiums[15,16,17,18] on computer aided ship design and production have been conducted regularly for information exchange and technology promotion.

4.1 U.S. NAVY[8,19]

The Navy has been actively involved in the application of computers to the ship design and construction process since 1950. Early efforts by the Bureau of Ships were directed toward exploiting the advantages of analog computing in the solution of many types of dynamic problems, from vibration analysis to control systems studies. By 1960 Navy shipyards possessed their own computers, and programs were developed for engineering computation and for business management. These programs were later developed into a large information management system for all Naval shipyards. In 1964, the computer aided ship design and construction

office (CASDAC) was established at the Naval Ship Engineering Center (NAVSEC) with DTNSRDC assigned lead laboratory status. The Navy commitment had been formalized to the extent that the entire CASDAC effort was covered in a Naval Ship Systems Command Technical Development Plan (TDP) as discussed by Nachtsheim and Ballou.[20]. However, the funding for this program was severely restricted so that work has been accomplished mostly in the area of concept formulation, except for two large systems for detail design. These two systems and other major accomplishments and developments are described in the following paragraphs.

- Integrated Ship Design System (ISDS)

ISDS[9] is a large subsystem of the CASDAC integrated system. It is an attempt to provide a mechanism to assist engineers to more rapidly synthesize a ship in the ship concept formulation phase and to exchange information required by different disciplines in ship design. The system is being developed at DTNSRDC for NAVSEC.

The completed ISDS will eventually consist of 30 operational program modules sharing a centralized data base. ISDS is supported by an extensive software system, the Computer-aided Design Environment System (COMRADE),[21] which was developed concurrently at DTNSRDC.

ISDS operates primarily in an interactive mode from teletype terminals or graphics scopes. Extensive interactive graphics software has been developed and incorporated. A set of user-oriented commands is provided and ship design operations are conducted by engineers under control of a project leader. ISDS will change the current method of operation from the execution of individual application programs with manual reformatting of input and output to an integrated information exchange and program execution environment. The system will, when completed, reduce the time required for concept formulation from the currently required several calendar months to a matter of weeks. ISDS is currently in a skeletal form with 12 operational program modules. The system is now undergoing test and evaluation at NAVSEC.

- Computer-Aided Piping Design and Construction (CAPDAC)

CAPDAC,[10,22] a major component of the CASDAC program, will be a computer based system for the design, planning, and fabrication of

Navy shipboard piping systems. It will address the computerization of the piping process involving requirement analysis, design, planning, and outfitting. The system is being developed for use by NAVSEC, design agencies, and shipyards. A Navy/Industry Advisory Committee was established in 1973 to ensure that the system developed will meet the requirements of prospective users.

The complete development of the CAPDAC integrated system will take many years. The application programs will be developed first, based on a priority sequence, as "stand-alone" program modules or sub-systems for immediate use in ship design and production work. As the modules are developed, they will gradually be incorporated into the CAPDAC integrated system in a "bottom-up" implementation fashion.

- Computer-Aided Structural Detailing of Ships (CASDOS) System

CASDOS[23] is the largest and most ambitious computer-aided detail design project sponsored by the Navy during the period from 1964 to 1970. The system, which was developed for NAVSEC under a contract with Arthur D. Little Inc., takes the output information of the contract definition phase of the design process as input. The system details the ship structural portion according to the specification criteria, after which detailed data are translated into information needed to fabricate the hull structure. Output of the system consists largely of detailed working plans, numerical control tapes for flame cutting and welding, bills of materials, etc. This system has been used for structural detailing of four LSD vessels.

- Computer-Aided Ship Electrical Cabling/Wiring System[24]

This is another large system for detail design which was developed for NAVSEC by Westinghouse Electric Corporation in 1965 and which seeks to integrate the design, planning, and production of shipboard electrical cabling and wiring. The principal objective of the system is to automate the documentation required by fabrication and installation workers. Such processes as voltage drop calculations and cable routing are performed by the system. The designer is also assisted by automated lookup of equipment catalog information. Planning and estimating sheets are prepared to assist in procurement of material and preparation of job orders. This system has been implemented in

several Naval shipyards for use in new Naval ship design as well as overhaul.

Rapid advances in computer science technologies and the changing environment in which Navy ships are designed, constructed, and procured have made necessary a revision of the early Navy plan[20] completed in the late 1960's. The Navy decision coordinating paper[25] for CASDAC, which was formulated by NAVSEC in 1977, recommended complete design and implementation of a computer aided ship design and construction system over a nine-year period with a total of $80 million. The NAVSEC report[26] includes a cost/benefit analysis for the development of a CASDAC system. However, the scope and detail of this complete system are yet to be defined and funding for this system has not yet been appropriated.

In addition to the CASDAC effort the Navy has engaged in the development of a Shipyard Management Information System (Shipyard MIS)[11] for all Naval shipyards. Early in 1961, the Bureau of Ships (now part of NAVSEA) sponsored the development of a new management system for Naval shipyards to improve management control techniques and to emphasize processing. The Shipyard MIS is an integrated system for providing essential information for better planning, scheduling, and control of production work. The Shipyard MIS was developed jointly by the Bureau of Ships and seven Naval shipyards. Each of the shipyards was assigned a major application for completion. The system is composed of four subsystems: financial, industrial, material, and administrative. It has been growing and expanding continually since its initial pilot implementation in one Naval shipyard in 1965 and is now in operation in all eight Naval shipyards. Better exchange of information among the Naval shipyards is now possible, because of common data terminology and data format. Reports are produced in a standard format.

The Shipyard MIS has provided an effective information system to support the repair and modernization of Navy ships in Naval shipyards. Effort has been underway since 1975 to adopt more advanced computer science techniques so that the system will better serve both the operation and management of Naval shipyards and to redesign the system to increase its potential in support of ship repair and modernization.

4.2 MARITIME ADMINISTRATION

Following the enactment of the 1970 Amendment to the 1936 Merchant Marine Act, the Maritime Administration (MARAD) was given responsibility to implement programs which would improve the productivity of the shipbuilding industry. These amendments set in motion a ten-year federal program to rebuild the American merchant marine and to reduce the shipbuilding industry's dependence on subsidies.

The MARAD, in cooperation with the shipbuilding industry, launched a national shipbuilding research program.[27,28] During the five years from 1971 to 1976, programs were funded by the government at a cost of $15 million, and industry contributed manpower, material, and facilities in excess of $5 million. These programs included production automation, welding, material handling, production procedures, etc.

The Research and Engineering for the Automated Production of Ships (REAPS) program[29] is one of the major programs sponsored by MARAD, administered through IIT Research Institute (IITRI). The objective of this program is to achieve coordinated development and implementation of computer aids to production within the shipbuilding industry. REAPS uses a systems approach to identify and take advantage of productivity opportunities through the application of automation technology.

REAPS is a cooperative development program of the shipbuilding industry and government. Projects to be pursued are first identified and then recommended by REAPS representatives, who are personnel from participating shipyards. If the proposed project is accepted by MARAD, a cost sharing contract is issued to the performing yard. Once a project is initiated, a Project Advisory Group is formed consisting of a number of yard personnel. The function of this group is to advise the performing shipyard on technical and operational considerations and to ensure that the delivered product will meet other yard requirements.

The major effort of the REAPS program prior to 1975 involved the maintenance and enhancement support of the AUTOKON-71 software to which MARAD acquired the rights from Norway in 1971. This effort also included the documentation of enhancements developed by the participating shipyards and IITRI.

Other projects supported by REAPS include an automated pipe detailing system, a damage stability program, a hull definition program, a graphics and communications terminal system, a parts definition system, a cold twist structural forming system, and a steel working device.

In order to broaden the technical base and to enhance the portability of common technology across a wider range of U.S. shipyards, the REAPS program was redirected in 1975 to include the following objectives:

- Advanced planning for future productivity opportunities
- Library and information services to apprise the industry of the latest available information on technology
- Research and development program formulation

The REAPS program has been successful in providing automation aids and promoting advanced automation technology to the U.S. shipyards. In addition, it provides a forum for personnel from shipyards to discuss their problems and exchange technical information. The 1978 REAPS 5th annual symposium[30] was attended by over 200 people, including some from Europe and Japan.

4.3 U.S. PRIVATE SHIPYARDS

Shipbuilding is one of the oldest construction industries and has developed many restraining traditions over the years. Use of new and different methods or approaches has often been opposed in favor of the tested traditional way of doing things. In recent decades, the size of ships has increased and the technology involved in their design and construction has become more complex. New types of ships, such as liquified gas carriers, large oil carriers, and RO/RO (Roll-on/Roll-off) ships, have required changes in the materials as well as in the techniques and philosophy of design and construction. The use of computers has assisted greatly in the changeover,[31] but the introduction of computers into shipyards in this country has been slow. In engineering disciplines, their use has generally been limited to repetitious, tedious types of calculations.

The United States has lagged behind Europe and Japan in using computers in the ship construction field. Flame-cutting of steel plates under numerical control was developed in the early 1960's by Norwegian and Swedish shipyards. General use in the U.S. shipbuilding industry did not occur

until the middle 1960's. One reason that Europe and Japan have forged ahead has been that government help and money have been used to develop computer systems for ship construction. With such assistance and leadership, large systems can be developed and improved.

In U.S. private shipyards, several large systems, some of which were developed in European countries, are now being used cost effectively. Their use is largely confined to the generation of numerical control information for ship hull plate processing and to business operations. The most important of these are described in the following paragraphs.

- The AUTOKON system[12] was initiated in 1960 by the Central Institute for Industrial Research of Norway as a cooperative effort with the Aker Group shipbuilders of Norway to develop a set of computer programs for numerical control of steel plate cutting. The first generation of this system was gradually brought into use during 1963-1965. Since then, the system has been improved and applied to various types and sizes of ships. The Quincy Shipbuilding Division of General Dynamics in 1965 was the first American shipyard to acquire the system. AUTOKON is a large software system whose programs share a common data base. It is primarily a system for computerized lofting and numerical control cutting of ship hull plates.

  A considerable extension of AUTOKON took place in the years 1966-1970 and resulted in the AUTOKON-71 version. In 1971, MARAD acquired the U.S. license for AUTOKON-71 for U.S. shipyards. Currently, at least five American shipyards and many other shipyards worldwide are using the system. A newer version, AUTOKON-76, was recently introduced.[30]

- SPADES (Ship Production And Design Engineering Systems),[13] developed by Cali & Associates, Inc. (Metairie, Louisiana) in the early 1970's, is also primarily a system for generating numerical control information for ship hull plate cutting. The system has complete lofting capability and also includes some engineering aid for ship design and production. SPADES consists of several program modules which share a common data base. The system is being used by at least four major U.S. shipyards and provides services for many other smaller shipyards.

• SPARDIS (Scheduling Planning and Reporting Data Information System)[14] was developed at and is being used by National Steel and Shipbuilding Company (San Diego, California). It is designed to assist in the scheduling and planning associated with the production of ships and is intended to provide various levels of production management with the information to better perform their function. The SPARDIS system is in the form of on-line, real time, data inquiry and update programs. Data are collected, updated, and maintained for the system through interactive terminals located throughout the shipyard at strategic locations where the data are originated and used.

• STEERBEAR[32] was developed at Sweden's leading shipyard, Kockums, beginning in 1962. The capabilities of Steerbear include all the usual hull application programs such as hull form definition, shell plate expansion, plate parts programming, NC tapes for flame cutting, material lists for steel bending information, etc. Steebear comprises a large number of subroutines which share a common data base, enabling the hull data to reference one another. Steerbear is being used by one major U.S. shipyard and some other shipyards in Europe. In Kockums shipyard, Steerbear has been integrated with an administrative system (System Q) and the capabilities of the system have been expanded to include piping and machinery.

A number of other computer-aided systems such as BRITSHIPS,[33] FORAN,[17] VIKING,[34] and NASD,[35] have been developed and are being used in foreign shipyards.

According to our study, ship design in this country is still largely a manual process. Computer science technology in general appears not to have been adequately applied by the shipbuilding industry. Hindrances to wider use of computer technology appear to be the high costs of software development and hardware procurement, the lack of incentive for the capital investment needed to apply computer technology, and the modest level of coordinated effort in software development in the shipbuilding industry.

Major improvements in pre-contract design can be accomplished through integrated, interactive ship design systems,[36,37,38] which will tie all application programs together for sharing a common data base and for using computer drafting devices to produce engineering drawings. Such systems

will allow more trade-off studies in a shorter time, a crucial element in the pre-contract ship design stage. In the post-contract design stage, a large percentage of the ship design detail processes can be automated to reduce design cost and time. It is suggested that computer science and technology advances are needed to support large integrated Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) system development, to make software development and maintenance easier and cheaper, to make CAD/CAM systems easy to use and cost-effective, and to automate large parts of the production process.

4.4 ECONOMIC AND TECHNICAL BENEFITS

Engineering design is a process of analysis and decision making to produce information which will ensure correct manufacture. Computer aided design (CAD) and computer aided manufacturing (CAM) systems are used to improve analysis computation, decision making, communication, information processing, and manufacturing operations. A well-planned and well designed CAD/CAM system will result in considerable reduction in design and production cost and time as well as in an improved product.

The costs incurred in the design and manufacture of a product are generally low in the early design stage and high in the production stage. On the other hand, the relative importance of the decisions made at each stage is just the reverse.

A computer aided ship design system provides tools for making trade-off studies quickly and easily in the early ship design phases. The system frees engineers from many laborious computation and data collection tasks and makes it possible for them to review many more alternative designs in their search for the optimum design.

Data compiled from NAVSEA show a typical summary breakdown of the Navy's annual cost (1968) of new construction as follows:

Design --5%

Construction-------------------------------------95%

Labor--------------------------------29%

Material and Equipment---------------66%

It is unusual for reduction of design costs to be the main reason for implementation of a CAD system, because the return from CAD is not

primarily in the reduction of design cost. CAD is necessary to gain the most benefit from CAM by savings on labor, material, and lead time and at the same time to produce a better product. Therefore, attention should be directed to better design for production which will result in saving time, labor, and material in the production phase.

To determine the economic benefit of computer aided ship design, NAVSEC recently completed a study[26] based on the design process analysis of a Guided Missile Destroyer (DDG) performed by Gibbs and Cox Co.[39] Each design phase was further divided into a number of tasks. The Gibbs and Cox analysis[39] reported the number of mandays involved in performing each task and the distribution of the estimated mandays among five functions: calculation, creation, drafting, data management, and specification preparation. Very few tasks were automated at the time (1968-1971) of that study. NAVSEC's study developed "reduction ratios" for each cost to show the effects of developing computer programs to assist the designers and engineers in accomplishing their tasks.

NAVSEC's study[26] concluded that the total cost (FY 1977 dollars) and savings for each phase of design of a typical DDG-type ship would be:

	Manual($K)	Computer Aid($K)	Savings($K)	Savings(%)
Preliminary design	265	133	132	50
Contract design	2,197	1,123	1,074	49
Detail design	26,787	10,241	16,546	62
TOTAL	29,250	11,497	17,753	61

This table shows that the total savings achieved in the design phases of a DDG ship through the use of computers in place of conventional manual methods would be about 60 percent.

NAVSEC realized calculated savings of $18 million[40] in 1972 and $67 million in 1976 in ship design through the use of computer aids. In addition, many Navy developed computer programs are being used by private shipyards and design agencies.[41]

Savings in ship construction effected by using computer aids and automation are also reported, for example, by Newport News Shipbuilding and Dry Dock Co.,[42] which indicate that better design for production resulted in faster and more accurate assembly that did not require skill levels as high as those previously needed.

NAVSEC's report[26] concluded, using a typical DDG as a model, that administrative lead time could be reduced by 25 percent and that design and construction costs, exclusive of government furnished equipment and material, could be reduced by 15 percent.

The following additional benefits have been identified:

- Improved quality of ship

  Use of computers allows more sophisticated models to be considered and analysis calculations to be incorporated early in the design process. Ship performance, structural integrity, acoustic properties, etc., can be predicted more reliably at earlier stages in.design.

- More consistent design

  Design inconsistencies are reduced by maintaining a completely integrated ship data file for each ship. Design or construction changes required can be made more quickly and less expensively through ready access to the ship data file and the use of computer graphics.

- Fewer change orders through reduced lead time

  Current lead time for combatant ships from concept design to delivery is of the order of eight years. This long lead time often results in change orders that cause cost overruns in ship acquisition.

- Increased precision of fabrication and assembly

  Numerical control technology has increased the precision of fabrication and assembly. This work can now be handled by less skillful people or by automatic machines.

- Improvement in maintenance and retrofit processes

  Ship maintenance and retrofit processes would benefit from ready access to a complete detailed ship data file created in the design and construction stage for each ship and throughout its complete life cycle. The planning and design modification work would be greatly simplified.

- Performance of more work by people with fewer special skills

  Shipbuilding requires competent, experienced personnel in design and fabrication. Fluctuating workload has caused large numbers of skilled craftsman and ship design engineers to move to other industries. This problem cannot be solved by more hiring, because the necessary talent is not readily available.

- Improved acquisition process

  The effectiveness of the acquisition process is improved by an orderly basis for system integration through design, evaluation, performance prediction, specification development, and proposal review in all phases of ship design.

4.5 OTHER RELATED PROGRAMS

Three large related software programs, Computer Aided Engineering and Architectural Design System, Integrated Computer Aided Manufacturing,[43] and Integrated Programs for Aerospace-Vehicle Design,[44] currently sponsored by the Army, Air Force, and NASA, respectively, are under development. The outcome and success of these developments will have great impact on the future development of computer-aided ship design and production systems. Close coordination with the development of these three programs is suggested.

- Computer Aided Engineering and Architectural Design System (CAEADS)

  This system, being developed by the U.S. Army Construction Engineering Research Laboratory, is to be an integrated set of computerized tools to assist the planner and designer of construction projects. The objective of CAEADS is to improve the quality of engineering and architectural design and reduce costs and time.

  The system development covers the period from 1978 to 1983 with a $10-million estimated budget.

- Integrated Computer Aided Manufacturing (ICAM)

  ICAM, a long-term development effort in the Air Force, is intended to accelerate the establishment of a total integrated computer-aided manufacturing environment for use by the aerospace industry.

  The initial implementation of the Sheet Metal Forming Subsystem is a five-year, $75-million effort.

- Integrated Programs for Aerospace-Vehicle Design (IPAD)

  The objective of this project is to develop a computer software system for use by the U.S. aerospace industry in the 1980's in the design of future aerospace vehicles. This system, an engineering information processing system for aerospace design, is to be

installed in major U.S. aerospace companies to provide a computer based capability to reduce design time and costs and to improve vehicle performance.

IPAD is being developed by Boeing Commercial Airplane Company for NASA Langley Research Center and is approximately a $12-million, five-year (1976-1981) effort.

5. A FUTURE CONCEPTUAL COMPUTING ENVIRONMENT FOR SHIP DESIGN, PRODUCTION, REPAIR, AND MANAGEMENT

Rapid advances in computer related technologies have made it possible to consider developing a conceptual computer aided ship design and production system (hereafter referred to as a conceptual system). Such a system would provide an overall strategy and discipline for enhancing all areas of ship design, repair, production, and management. These developments have the potential to grow to a very large and complex, integrated but manageable, CAD/CAM system. Such systems could greatly reduce ship design and production costs, and at the same time improve quality.

A conceptual system may be viewed as a systematic integration of computer hardware, software, and application programs. This integration will help engineers to conceive, explore, design, optimize, procure, and produce new ships smoothly and efficiently in an advanced computing environment. The basic intent is to exploit the capabilities of computer technology to enhance ship design and production activities. The approach is to identify and analyze the functions required to support the essential elements of design, production, and management activities and to try to realize the corresponding functions in the field of computer technology.

The full capabilities of such systems will depend largely on future hardware and software technology development. The future computer environment can be expected to be a more intelligent one. A typical computing environment of the 1980's may include more advanced operating systems and computer hardware, computer networks in which both program modules and data files may be shared and transferred from one processor to another, and processors which have direct access to data in the memory of other processors. Development of mini- and micro-computers and communication technology will play a vital role in such configurations.

NAVSEC has proposed the development of a <u>near-term</u> integrated Computer Aided Ship Design and Construction (CASDAC) system in nine years with an estimated budget of $80 million.[25] The CASDAC effort can take full advantage of the results of the research and development program proposed here, provided that the CASDAC application programs developed are modular, portable, and, most importantly, sufficiently independent of the data base structure.

The purpose of this chapter is to explore the requirements on the future computing environment to support the development of the conceptual system. Such a conceptual system is described which will provide the computing environment to meet future needs.

5.1 GOAL

The goal of the conceptual systems is to provide computer based capabilities to substantially reduce design and production time and costs while improving production quality and vehicle performance. They will provide means of communication, information exchange, numerical computation, budget and production schedule control, and machine operation while supporting large numbers of workers conducting a broad range of design and production tasks over significant periods of time and on a wide range of marine vehicles. They will also increase the effectiveness of individual workers by improving their work environment.

In the ship maintenance and repair process, such systems will provide ready access to a complete detailed ship data file and simplify repair and overhaul work.

5.2 REQUIREMENTS

The proposed conceptual systems will provide the following functions:

- ship design and analysis
- ship production engineering
  - material ordering and inventory control
  - production planning, scheduling, and monitoring
  - material preparation, ship assembly, and outfitting
- ship repair planning, design, and monitoring
- overall activities management and coordination
  - contract administration
  - forecasting and performance evaluation
  - cost estimation, budget control, and financial bookkeeping
  - pay roll and personnel information management
- repository for all up-to-date information relating to ship design, production, and repair
- communication link among co-workers, ship owners, material suppliers, subcontractors, other shipyards, and institutions.

5.3 SYSTEM OVERVIEW

Meeting the Navy's missions requires sophisticated ships, weapons, communications, propulsion, structures, and other components, all of which are highly interdependent. Ship design and production processes have become more and more complex, requiring the contributions of many specialized disciplines and spanning many years.

At the beginning of the ship design process, a set of requirements is identified in the areas of mission, speed, payload, etc. The designer's goal is to minimize the cost of ship acquisition while meeting these basic requirements. The designer applies his accumulated experience and knowledge, with intuition and creativity, to the requirements and constraints he has been given. While intuition and creativity are not easily delegated to a computer, much of the designer's knowledge and experience can be, so that a large part of the ship design, production, and management process can be automated with application software, and the designer can be provided with a much more stimulating and supportive environment.

The result of the ship design process is a single product in which all the components must function harmoniously. Hence extensive data communication, evaluation, and iteration are required to optimize the design. Since a change in the design of one component often results in the redesign of many other related components, orderly methods for introducing changes in the design are necessary. These methods require a comprehensive and efficient data handling environment, and thus the data management and application software functions form the backbone of the conceptual system.

5.3.1 Integrated System

Although the computer has been utilized in the Navy shipbuilding industry for a number of years, this utilization has, for the most part, been confined to substitution of the higher speed calculating ability of the computer for the slower manual methods previously used. The use of the computer to replace manual methods has been pursued largely on the basis of "cost-effectiveness" or "pay-back" in a reasonable time. Consequently, the development of computer application programs to aid ship design and production has proceeded mainly in an independent, modular, or subsystem fashion.

The early successes with calculation automation on simple tasks naturally led to putting more complex tasks on the computer. These more complex tasks inevitably resulted in data handling problems, especially at module interfaces. Furthermore, design staffs are usually large and involve various groups of specialists. In the detail design phase, for example, several hundred people may work simultaneously on numerous major components of the ship such as hull structure, weapon systems, machinery, piping, and communication. The design process involves the transfer of large quantities of data and multiple interactions among different groups of designers. This lateral communication involves translation of design data and concepts onto drawings and the transfer of these data. Very often one group's design is constrained by another group's requirements. The size and complexity of this cumbersome process make it difficult for designers to maintain continuous access to, and exchange of, appropriate and up-to-date information for the conduct of their respective tasks. It is also difficult to maintain a smooth flow of information between tasks and from one level of design to the next.

While computing speeds have increased dramatically, the effort and time required for the tedious tasks of information gathering, input data preparation, transfer, and interpretation are major obstacles to more effective use of computers. The integration of applications programs into a system to share a common data base avoids many of these difficulties and results in increased productivity. System integration has been used to facilitate data flow among program modules or subsystems and to eliminate manual data reformatting. Therefore advanced integrated design systems are being developed to relieve the constraint of communicating large volumes of data across module or subsystem interfaces. Data can be transferred across modules or subsystems by developing compatible data formats and passing the data through the computer system directly. In this way modules will be able to communicate technical data reliably, precisely, and instantaneously. An integrated system can be effectively configured to coordinate related design disciplines and to monitor program execution sequence. It will thus provide a medium for exchange of data and a common reference system for problem solution and design development.

5.3.2 System Organization

A conceptual system is a totally integrated system oriented to the design/production/management process. Such a system as presently conceived has five major components, as shown in Figure 1.

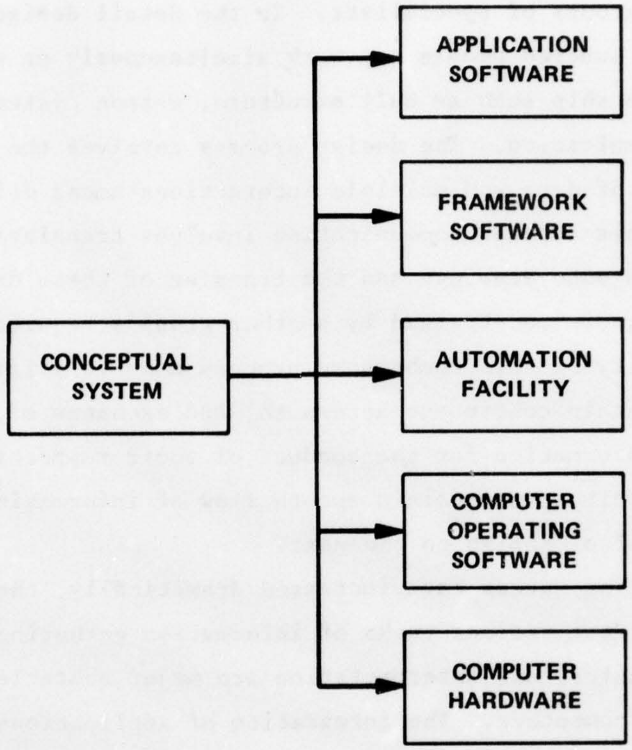


Figure 1 - Organization of a Conceptual System

• Application Software: An open ended library of computer application programs or modules for various design/production/management disciplines. The application software can be logically divided into three groups: analysis/design, production engineering, and business management. Figure 2 gives an overview of the interrelationships and data flow among the three groups and five related data files. These three groups of application software are described in Section 5.4.

• Framework Software: The framework software is primarily an augmentation of the computer operating system. Ship design involves a complex hierarchy of processes and extends over a long period of time. The framework software must provide a facility for information continuity over

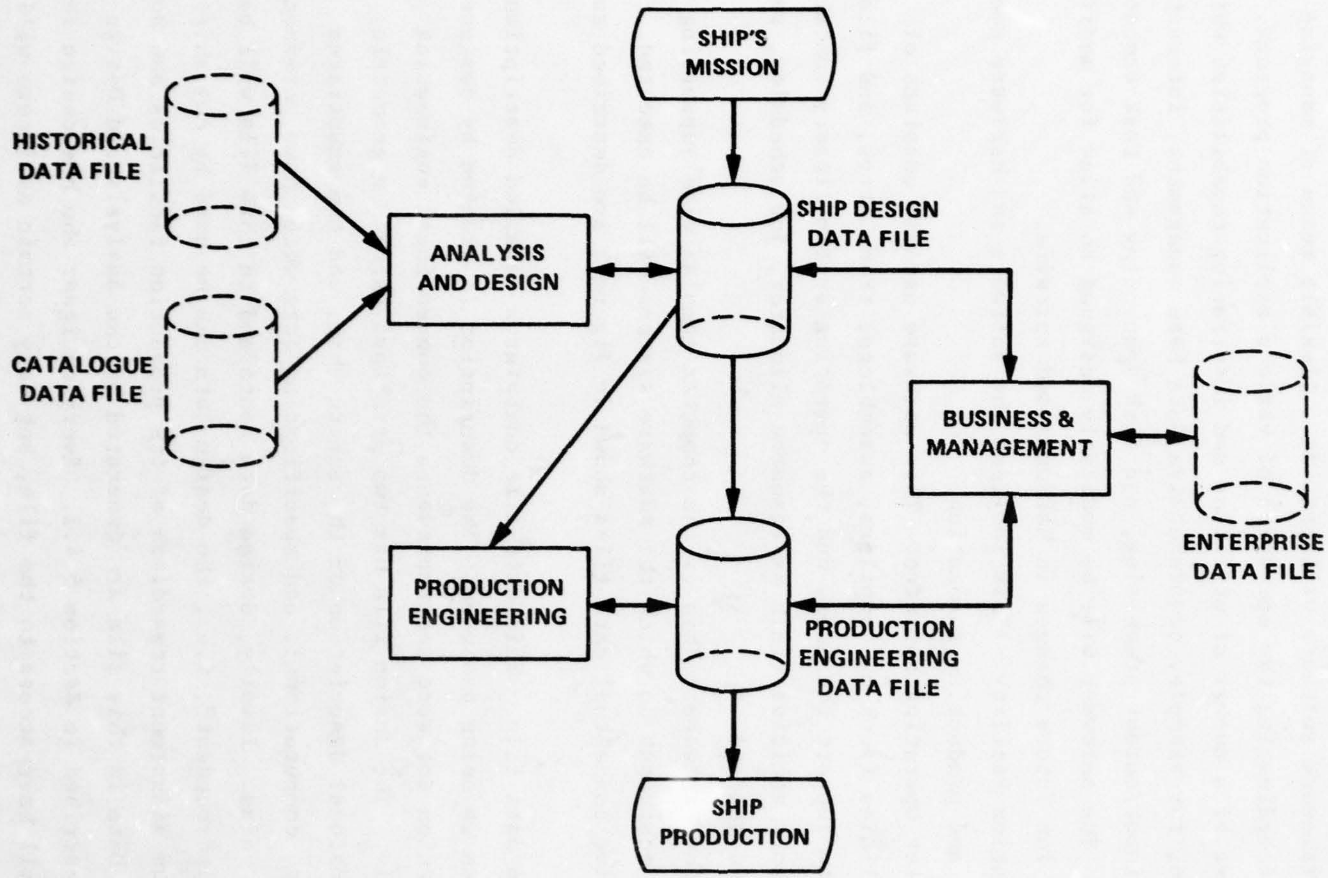


Figure 2 - Application of Software and Related Data Files

tasks and time, which is not usually provided by the computer operating software. Without this added dimension of support the system cannot, in the fullest sense, provide the capability for integration of design tasks.

The framework software will provide a flexible means of managing data files and coordinating the operation of various application programs. It will consist of a number of utilities and interfacing capabilities which may include, for example, comprehensive data base management, interactive graphics, input/output processing, and task sequencing and task executive functions. The software will be modularly designed to allow for modification and for future changes in hardware and software.

- Automation Facility: This includes the software and hardware used for design and production automation.

- Computer Operating Software: This software usually consists of system utilities (such as compilers, assemblers, translators, and file managers) to support the user, and the operating system library containing system support entities (such as resource allocator, job scheduler, record manager, and loader).

- Computer Hardware: This is the computer complex with supporting peripheral equipment on which the software systems will be executed.

The five conceptual data files shown in Figure 2 are described as follows:

- Design data file. This data file contains a detailed description of a ship which is being designed. The description is created by designers via application software and represents the conventional engineering drawing file. The design file has two principal parts: a geometric three-dimensional description of the entire ship; and the associated engineering, computational, and specification data which have permanent or interim value. Ideally, design data contained in this file will be "shipyard-independent", i.e., the design data can be used by any shipyard with minimum adjustment regardless of its production facilities and constraints. Data in this file are generated by the Analysis and Design Software described in Section 5.4.1. Every designer who has design responsibility will have access to the file, but only certain designers will have authority to add to or modify it. The maintenance of data file integrity,

consistency, and security under conditions of use by multiple users and a concurrent access environment is essential.

- Catalog data file. This file contains two types of data. The first type includes design rules, criteria, and specifications. The second type includes descriptions of materials (such as metal plates, pipe, and cable) and component or equipment parts (such as machinery, weapon and electronic gear) which may be procured for assembly and installation. The file must contain identification and properties of each item and will need periodic updating to keep it current.

- Historical data file. This data file is the repository of all technical, statistical, and other data that have been accumulated from previous ship designs and studies and that are a vital part of the experience of a design team.

- Production engineering data file. This file contains information concerning the production of a ship, which will include, for example,detail data and instructions on material preparation, ship assembly erection, and outfitting, and work schedule control and coordination. Some data in this file are generated by the Production Engineering Software described in Section 5.4.2 and some are transferred from the Ship Design Data File. Some data in this file are constrained to the individual shipyard's facilities for optimum producibility.

- Enterprise data file. This file contains data for the business and management of the entire enterprise (see Section 5.4.3).

5.3.3 Operating Environment

The most important characteristic of this system is that the designer, who communicates with the system through the terminals, has complete control over significant transactions in design. His experience and judgment are preserved; he has the capability to construct and manipulate the ship design data file via commands to the system to perform, accept, reject, or modify system performance, and to provide interpretations or supplementary data to the system. The system behaves like an engineering aide with some reasoning and automating capabilities.

The system will be so organized that users retain the visibility and control necessary to exercise their intuition and imagination in

the ship design and production process. Such a new environment will facilitate tasks for all users and make possible an exploitation of the user's creativity and of computer technology to benefit the total ship design and production process. However, such a system can be justified only on a cost-saving and better-product basis.

The system will support a large number of interactive users, each working on a part of a design task. The interactive terminal will be the primary interfacing device between the user and the system. The system will allow the user to create and modify sketches and drawings at a graphical terminal; it will also make related calculations and produce engineering designs. The system will also support management in retrieval and display of project technical and management information for regular reviews of work progress, schedules, resource utilization, etc.

The system will be conceived and designed to enhance team creativity through effective communications and interactions among team members. An individual user will participate in the design process in an interactive environment. A task may be performed by one individual or by several members of a design team, involving one or more engineering disciplines, working interactively or sequentially. The integrated environment may involve several users in sequence or in parallel.

The success of such a system is closely related to the effectiveness of the interface between the system and the user. A well-adapted command language will play an important role here. The user will be provided with a set of commands by which to control the operation of the system. This command language will be oriented to the user to enable him to utilize his knowledge and ideas without being disturbed by a dialogue with the system which seems unnatural to him. By using the commands the user will be able to sequence and execute program tasks, to access or modify the data base, and to operate the system.

The system will require use of advanced data base management concepts that can cater to the total design, production, and management process. A full spectrum of logical data structures will be available to the user. The logical data structure as seen by the user will be entirely independent of the physical storage structure. Methods will be provided for controlling access to data bases, including protection of integrity with concurrent

user access, and for detecting errors. The system will provide for continuity of data base growth over the tasks involved in design and production.

The system will include the capability, through networked computers, to carry out computations and to access information at computers away from the user's work site.

The system will also provide appropriate means for accessing project data several years after its archival storage on tapes, microfilm, disc, etc.

5.3.4 System Development

Past software development practice has tended to start with coding of program modules and then work back to the system design and requirements analysis. The method worked well for relatively small projects but caused chaos in large system development.

The development of large systems has been, in general, substantially more complicated than the development of small ones. There is more logical designing and checking to do per unit of program developed; more people are required to do it, and to coordinate their efforts; and each person spends more time communicating and less time producing.

There are seldom problems in developing the programs or the modules for large systems. Difficulties more often show up at system integration time; all the modules seldom run together as designed. An additional difficulty is often that, when the system does finally run as designed, it does not do what the users need. This indicates that specification and requirements analysis were not properly handled at the outset or that the users needs have changed during the development process. There is no greater mistake than insufficient system requirements analysis.

The entire software development of the large system proposed here, from requirements analysis and system design, through implementation, testing, and maintenance, will be conducted and organized in an orderly, manageable way (Section 6.6). Effort will be directed to making the quality, performance, and cost of the software product predictable and to effecting an appropriate compromise between cost and reliability.

The steps recommended in the software development of the conceptual system are as follows:[45 46 47]

- Approach the development of the system through an overall system analysis of the entire ship design, production, procurement, and management process; develop an overall structure for planning the system and its long-range goal.
- Perform an in-depth analysis of the ship design, production, procurement, and management processes in close cooperation with the organizational agencies and personnel involved in the process.
- Design the entire system in sufficient detail so that a minimum prototype framework software can be developed to allow the existing and high pay-off application programs to be developed, converted, assimilated, integrated, and tested. This prototype system can then be used in a limited operational environment. In parallel, other application software can also be developed.
- Amend the system requirements analysis and modify the system design, if necessary, to augment previous design, correct design errors, and accommodate new user requirements and new development in computer technology.
- Continue the full scale implementation of the framework and application software. In the development of application software, include modern ship design optimization techniques such as finite element and fluid flow analyses.

Three topics, i.e., portable software, top-down design/implementation, and modifiable/maintainable software, are so important in the software development process that they deserve special attention.

Portable Software:

The ability to transport software systems among different computers and from one computational environment to another, with a minimum of software modification, is essential. Portability of software systems without accompanying sacrifice of much of the computer's power seems to be a difficult problem. However, advances in computer technology, such as those in networking and distributed computing, may obviate future need for concern

over portability. The development of a true generalized distributed computing system is still many years away. In the meantime, other means for achieving software portability are required.

Top-down design/implementation:

The necessity for top-down design and implementation in large software systems has been made evident by bitter experience with top-down design and bottom-up implementation. In bottom-up implementation, poor design is often hidden until late in integration, after much functional code has been written and tested, only to be discarded. In top-down implementation, the control programs that integrate functional modules are written and tested first, and the functional modules are added progressively. The implementation proceeds on an incremental basis, level by level, with testing and integration accomplished during the programming process rather than afterward. Top-down implementation is more difficult to design than bottom-up implementation, but the extra effort in design is compensated for during integration and testing. The problem of design in top-down implementation is not only how the final system will look, but also how the system under development will look at every stage of its development.

Modifiable and Maintainable Software:

In software system development, it was commonly supposed that programming or implementation was the main problem. However, today some 70 percent of data processing personnel are involved in maintenance, not development.

Large systems[48] usually require a significant time for development, even with the most meticulous requirement analysis, design, and implementation. The product as first released to its users does not, in general, possess precisely those functional characteristics and properties expected or desired in the application and user environment. Furthermore, additional user requirements or new ideas may surface and new hardware technology may be developed during the system implementation stage. These factors require that the system be corrected, modified, and extended after installation. Since large systems represent a substantial investment, there are

economic pressures to modify a product to meet new requirements of users and to adapt new developments in technology. Once operational, the system inevitably contains faults, design bugs, and implementation errors which must be corrected. The systems are therefore modified and the evolutionary cycle goes on.

Software modification and maintenance usually involve redesign which in turn may introduce further errors and are very likely to further increase the system's complexity and problems. The complexity grows until effort must be invested in restructuring. Eventually such a level of complexity is reached that further evolutionary progress can be made only through re-creation--replacement by a new system to satisfy the most recent operational requirements. Therefore, it is not sufficient for a system to be initially correct. Its structure must remain correct under a sequence of changes.

The initial assessment of large software systems must be based on life-cycle costs, not on the estimated cost of development and first implementation. Large systems seldom work properly as first implemented. A very high percentage (50 to 90 percent) of life cycle costs[48] of a large software system may be incurred in post-first-release enhancement, modification, and redesign.

5.4 APPLICATION SOFTWARE

The application software of a conceptual system can be logically divided into three groups as shown in Figure 2 (page 32). Each of these groups embraces particular functions, but the three groups will operate under the same integrated environment. Information produced by application software will be stored in one of the three logical data files; i.e., ship design data file, production engineering data file, or enterprise data file. Each of the three groups of software can be organized into a number of systems; a system, in turn, comprises a number of modules; and a module consists of a number of programs. In all, there will be several thousand application programs of varying degrees of complexity.

5.4.1 Analysis and Design

Ship design progresses from general concept formulation to the details of how a ship is assembled. Each design phase implies an iteration of the design to meet requirements and specifications.

Ship design is a top-down complex hierarchical process in which vast amounts of data are generated, evaluated, communicated, and stored. It is a highly developed technical discipline in which the decisions of many individual designers must be coordinated, integrated, revised and iterated. The existing technical analysis and design programs form a feasible base which requires additional significant development and augmentation with new programs. Progress made in recent years in mathematical modelling (e.g., structure, fluid flow field, etc.), in numerical analysis (e.g., finite element, finite difference methods), and in design optimization should be incorporated in the design and analysis process.

The ship design process, especially for the Navy, has traditionally been divided into three distinct major phases as shown in Figure 3: concept/preliminary design, contract design, and detail design. Usually, entirely different groups of people are involved in each of the three phases. This is indicative of the fundamental differences in the ship design process in each phase. Although in small ship design the same group of people may deal with two or more of the three design phases, the three phases are distinct in all large ship design projects.

- Concept/preliminary design, which is near the beginning of the design process, is a highly creative activity. The ship's mission is only broadly defined and the best ship systems for accomplishing the mission remain to be determined. Using technical knowledge, experience, judgment, and intuition, a designer creates a tentative solution. This solution must then be subjected to analysis to prove adequacy and technical feasibility. If the tentative solution is not acceptable, then the process is repeated until the best alternatives are apparent.

Although the quantities of data handled in this design phase are relatively small, the process is inherently unpredictable and may involve large amounts of information from many sources such as historical data files. Accumulating and retrieving this information is time consuming and

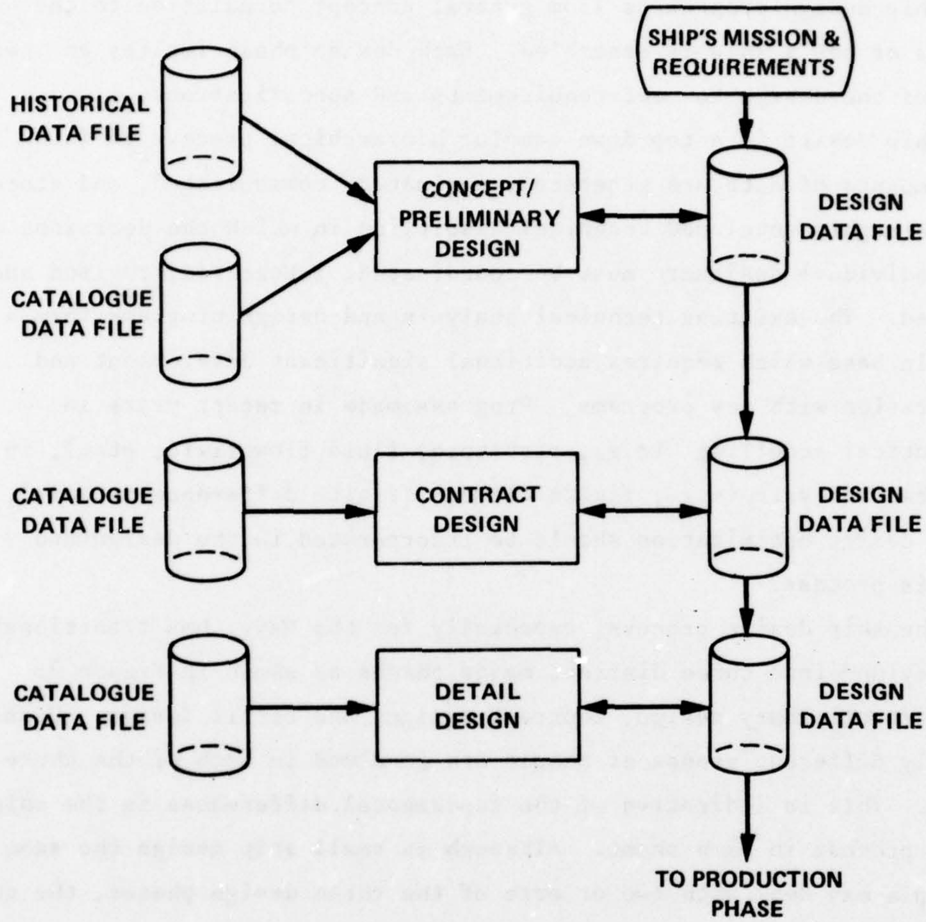


Figure 3 - Ship Design Phases

troublesome. A computer aided design system can assist the designer's efforts in the concept/preliminary design phase in such areas as data storage and retrieval, analysis computations for technical feasibility, computations for military effectiveness, and computations for trade-off analysis.

The advantage of computer aids in this phase lies not so much in saving the designer's time but in the expansion of the creative time available and in the ability to evaluate more alternatives in the relatively short period allowed. This increased range of alternatives should

lead to better final designs and improved effectiveness of the final product.

- Contract design follows the concept design phase and begins with a feasible solution to the overall stated problem. Still, investigation of the many alternative systems or components (i.e., hull, machinery, electric, weapon, etc.) which make up the entire ship is necessary, and substantial information storage and retrieval is involved. In addition, the design process requires many engineering calculations. The real advantages in computer aids at this stage are similar to those in the earlier design phase but pertain to ship systems rather than to the ship as a whole. Design activity in this phase can be characterized as the definition of systems of the ship in sufficient detail to permit a contract for production to be awarded. The design programs of this phase should be able to access and update design data developed in the previous phase. These design data should, in turn, be passed on for use in the next design phase. Greater numbers of designers are employed, and there frequently are problems in communicating design changes from one group to another. There is greater dependence than in the earlier design phase on the use of drawings in developing and communicating the design and increased computation in designing and optimizing.

- In the detail design phase, plans and instructions are developed, in compliance with the guidance and criteria from the contract definition phase, in sufficient detail to permit the workmen to assemble and erect the ship. As greater detail evolves, the design effort is characterized by the involvement of hundreds of people, and the tasks become more routine and repetitious. Also, large quantities of data must be handled. The computer aids are aimed at minimizing the cost of the engineering task itself by using the computer to increase the productivity of draftsmen, typists, clerks, and others. At this stage the overall geometry of the design, including component parts, is relatively fixed. There is less pressure for innovation; instead, the emphasis is on meeting schedules with a minimum expenditure of manpower. The principal role of the computer in this phase is to increase productivity and to reduce the time required for a given task. There are several ways to realize these goals. First, the ideas and results developed by a designer must be communicated

to others. The traditional means of communication has been, and remains, the engineering drawing. Planners, estimators, schedulers, and mechanics work from these drawings as shown in Figure 4.[35] A shipbuilding project can involve thousands of plans. The process of representing, updating, duplicating, storing, retrieving, and using these plans should be simplified and improved. Second, many of the time consuming and tedious routine design tasks can be computerized or automated; technicians and draftsmen should be employed here primarily to check and verify the computer output in graphical form. Computer application[12,13] to detail design and production so far has been limited primarily to steel work processing with minimum application to wiring and piping installation. Substantial work needs to be done on machinery, heating, ventilation, air conditioning, and auxiliary machinery, etc.

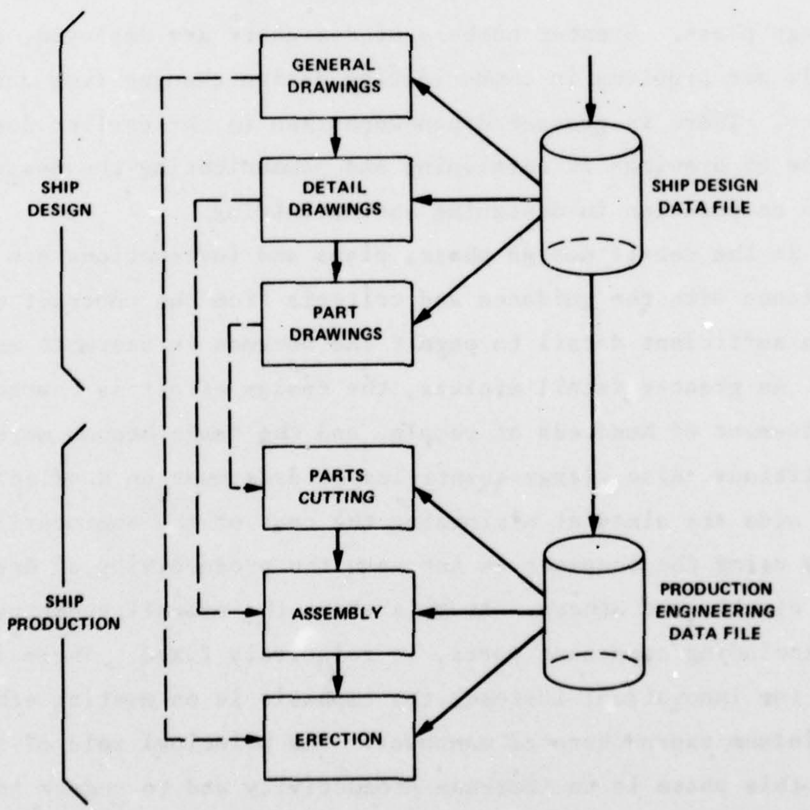


Figure 4 - Engineering Drawing Generation and Use

5.4.2 Production Engineering

On the completion of a detailed ship design task using a computer, the information generated becomes available in design data files to assist in the ship production phase. The advantages to the production phase of a computer aided ship design system provide sufficient justification for the entire computerized system. These advantages lie not only in the economies realized in the elimination of duplication between detail design information and production aids; numerical control (NC) of machine tools can provide a degree of accuracy not easily attainable with manual techniques. The ability to use such tools depends on the generation of accurate control data.

A ship is an extremely complex product, requiring the coordination of a great variety of skills, materials, and machines for its production. Design data must be transformed to NC information for material preparation and ship assembly and outfitting. Work planning and scheduling and material and equipment ordering must start months or even years before actual ship production work starts. The increasing complexity of production and material handling has made it quite clear that good work scheduling is essential to improve utilization of the assembly area and production facilities. Computer aids will enable the production planner to make better and more reliable decisions, to coordinate work among different disciplines, and to make changes, if necessary, more precisely and quickly.

Computer aided functions to be incorporated in the production phase for each ship should include

- Production work preparation, planning, scheduling, and coordination
- Material and equipment ordering and inventory control
- Material preparation; i.e., NC information for cutting and welding
- Work assembly, erection, and outfitting
- Generation of necessary reports and drawings for production work and management

Maximum or optimum size of a ship to be assembled is determined by the facilities of each shipyard. Most shipyards determine the erection sequence at the start of the contract and do not depart from this sequence. Schedules may be expanded or contracted to suit the workload of the yard,

but the erection sequence is not to be changed. When computer aided production systems are introduced into a shipyard, they must be adapted to the organization and to existing routines. The systems must be flexible and not impose restrictions or special considerations. A design which is optimum for producibility at one shipyard may not be optimum for other yards. Therefore, for a system to be widely used it must be flexible enough to be easily introduced into a number of shipyards and provide a productive operational environment.

In recent years, shipbuilding has made advances in mechanization and automation, and newly developed machines, production methods, and systems have been successfully introduced. These include automated plate supply systems, NC cutters, line welders, automatic panel assemblers, new material handling equipment, pre-erection assembly equipment, automated pipe shops, and various computer aided NC generating systems. Such new facilities and systems are changing certain aspects of shipbuilding. For example, sections are pre-assembled and transported from shops to assembly sites by sophisticated conveyor systems. Flow production systems have been introduced in which workers and machines are stationary while materials flow, thereby increasing productivity. This trend is more apparent in newer shipyards.

5.4.3 Business and Management

Application software in this area is to be used for the management[11] of an entire enterprise by a design agent, a shipyard, or a combination of the two. The business and management software will obtain necessary information from the data files of each ship being designed or produced and provide timely and essential information in usable form to all levels of management for the control and coordination of the operation of the enterprise. The functions to be included in the software are as follows:

- Planning, scheduling, coordinating, and controlling the overall activity.
- Forecasting manpower and material needs.
- Performance evaluation and quality control.
- Costing and accounting for labor and material.
- Paying personnel and recording personnel data.

- Report and documentation handling.
- Proposal evaluation and contract administration.
- Cost and time estimation for ship design, construction, repair, and alteration.

Figure 5 shows the relationship of the conceptual system to the large computer software systems currently being used in U.S. shipyards.

5.5 DESIGN AND PRODUCTION INTERFACES

In the more advanced parts of the shipbuilding industry, the production process in the assembly stage is similar to an automobile or aircraft assembly line, although the production rate differs because of the size of the product. However, there is a more fundamental difference between the shipbuilding industry and the automobile industry.[35] The shipbuilding industry is characterized by contract oriented or customized production, while the automobile industry is based on mass production. Under most favorable production conditions, shipbuilding can be characterized as multiple production but never as mass production. The difference alters the framework of the ship production process. It has, therefore, been necessary to have a wider range of communication between people in ship design and those in production, and to place more reliance on engineering drawings and the skill of individual workers.

Design activity precedes production. Traditional organizational, financial, and incentive systems have often tended to stress the separation of the design and production processes. The design section in the automobile industry is also rather independent from the production factory. However, ships differ from one to another, and this leads to a closer tie between ship design and production activities in a total production sequence. For example, production planning and preparation must be started long before the completion of the ship detail design phase. Engineering drawings have traditionally been regarded as an ideal medium of data presentation, storage, and transmission. More than ten thousand drawings are used for each ship.

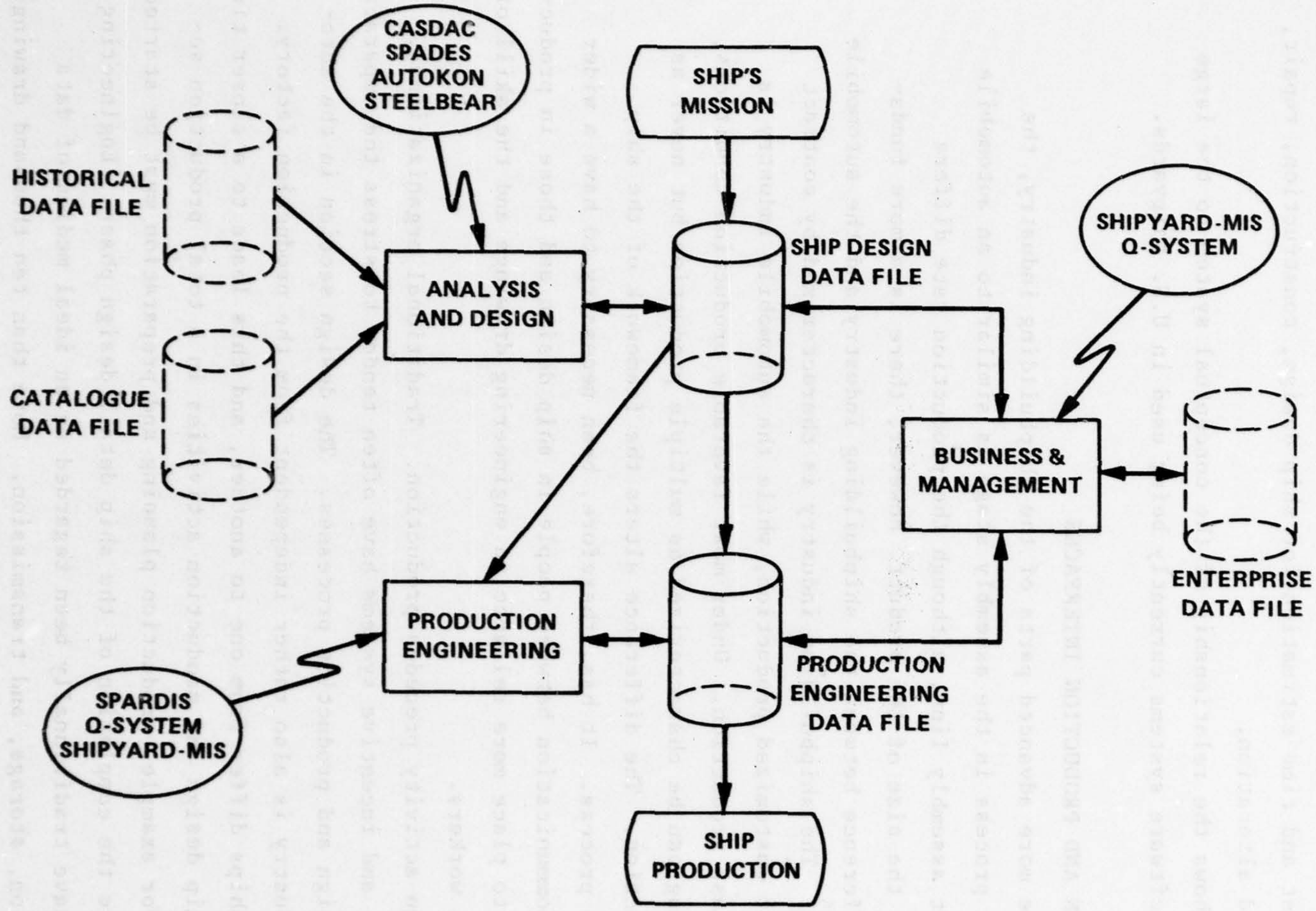


Figure 5 - Functional Relationship of the Application Software of the Conceptual System to the Systems in Current Use

The trend in the technology of data representation and transmission has been to replace hard copy drawings with ship design data files and computer graphics in an evolutionary progression. However, the computer has been required to produce drawings according to customary drafting standards and practices. This approach has imposed many unnecessary tasks on the computer systems; at the same time it wastes the potential of the computer as a readily accessible repository of design information, accessible through computer graphics facilities. More appropriate methods of presenting ship design data are needed.

Another mode of design-production interface is that imposed by manufacturing technologies which can be implemented only with the aid of the computer. In the design phase, the computer is introduced specifically to create input to the manufacturing technology; such input cannot be prepared manually. The nature of the interface in these cases is dictated by the equipment whose needs must be satisfied. Typical examples are the generation of input to guide numerical control equipment and other intelligent machines. In these instances drawings are generated as by-products for checking and repository purposes.

6. RELATED COMPUTER SCIENCE TOPICS

The previous chapter outlined a conceptual future computing environment which will greatly enhance the productivity of ship design, production, and management. The success of the development of such an environment for computer aided ship design and production is closely related to the proper application and future development of computer technology. Three main core topics in computer software in the support of a CAD system have been recognized:[49]

- Management of the data associated with the product to be designed and produced
- Interfacing techniques between the CAD/CAM systems and the user, i.e., computer graphics, interactive systems, command languages, input and output techniques, etc.
- Automation technology in design

In addition, three other topics have been identified here:

- Automation technology in production
- Distributed computing in the system design configuration
- Software engineering applied to the software development, maintenance, and acquisition processes

This section will discuss these six computer science topics and the need for their support to provide an environment for the development of advanced computer aided ship design and production systems.

6.1 DATA BASE DESIGN AND MANAGEMENT

A data base may be defined as a collection of interrelated data items stored together without unnecessary redundancy to serve multiple applications. If the function of a data base were merely to store data items, its organization would be simple. Most of the complexities arise from the fact that it also shows the associations among the various items of data that are stored.

The data base is structured so as to provide a foundation for application program operation and for future growth to incorporate more data. If the data base is not well designed, then it will have to be modified later as its usage evolves. This will necessitate the rewriting of

application programs. A major objective of data base design is to avoid the burdensome task of rewriting past programs as the system evolves. This implies that the data and the application programs which use them are sufficiently independent so that either may be changed.

A data base management system is a collection of software required for using a data base. Existing data base management systems can be classified into three major categories: hierarchical (tree), network (plex), and relational (table). One of the major differences among them is the type of logical data base structure.

The primary functions of a data base management system are to make the operation of application programs faster, cheaper, easier, and more flexible. The system is organized so that diverse applications with different data requirements can use the data. Different programmers and different users will have different views of the data which must be derived from a common overall logical data structure. Their methods of accessing the data will also differ.

Data base management techniques are significant for the storage and retrieval of the hundreds of millions of data items needed to specify an entire ship. The designer should be able to concentrate on design activities while the system manages and organizes the vast amount of data for him. It has been recognized that data base management software for the support of ship design and production is the most important and perhaps the most difficult software to be developed.

Ship design and production processes place some specialized requirements on the management of data by computer.[50,51] Such data bases are characterized by:

- Large size: A complete ship design data base is a digital description of the components of the ship and their interrelationships, to the level of detail required to support the production of a ship.
- Fast expansion: The data base grows from a few hundred words in the beginning of the requirements definition phase to a maximum size at the completion of the detail design phase. The expansion is faster than linear.

- Multiple Relations & Complexity: Most data items have several relationships to other data items. This means that each design discipline or application program will require the common data base to be structured in a variety of different ways, and will access the common data base for a different design purpose. A change of one data item in the common data base may effect many others.
- Dynamic Content: The engineering analysis and designs are usually tried and modified in searching for the optimum solution. The data base will, therefore, be constantly changing due to the dynamic nature of engineering analysis and design.
- Concurrent Access & Multiple Users: The data base will be accessed by hundreds of users concurrently. Maintenance of data base consistency and currency in the highly dynamic multiuser environment will be very difficult but essential.
- Wide Variety: The data base will serve a range of functions from scientific analysis and engineering design to preparation of bills of materials, inventory control, and production management. The data base will also be accessed by users in different ways from batch processing to interactive graphics terminals.
- Security: The data base will contain vital sensitive information on the ship and must be protected from unauthorized access.

Management of data has achieved maturity in many areas, such as banking transactions, airline reservations, and inventory control. However, the techniques used there are not well suited for managing the highly dynamic and complex data associated with engineering and scientific applications. There is a need to advance the technology for managing large volumes of interrelated dynamic engineering and scientific data.

In considering the future development of data base technology, two topics should be mentioned: Relational data structures[52,53] and the management of distributed data bases.[54,55]

The concepts behind the relational data base approach evolved as a result of trying to develop a more theoretical and rigorous foundation for the treatment of data. The main concept is embodied in the notion that, once the data is represented in a particular way, it is subject to operations described by relational algebra. This approach also offers a very

high degree of data independence and permits the data to be stored in a non-redundant form. While the relational approach offers a number of significant advantages, it currently suffers from a major drawback - performance. Most of the implementations to date have been on rather small data bases which exist mainly for research purposes. Future improvements in hardware specifically designed for relational operations and large content addressable memories should permit economical implementation of relational data bases for large engineering applications.

Distributed data base management has been made possible by advances in two areas: the development of low-cost computing equipment, and the development of computer network communication capabilities. A distributed data base can be thought of as the storage of data at different locations in a distributed system with interrelated data elements at multiple locations. Distributed data bases have evolved from the need to decompose very large data bases into physically dispersed units and to integrate physically dispersed, isolated systems for efficient management. The distributed data base management system approach offers these major advantages in applications:

- The system can be more reliable; it is not susceptible to total failure when one computer breaks down.
- It is possible to store portions of the data base near to where they are frequently used, resulting in fast retrieval.
- A very large data base may be supported on a collection of moderately sized data base management systems. To accommodate increases in data base size or usage, additional sites can be added without major service disruption and conversion costs.

Distributed data base management seems to be an attractive alternative to the centralized data base management techniques currently used by most large CAD/CAM systems.

6.2 COMPUTER GRAPHICS

In engineering analysis and design, especially for highly creative activities such as those which characterize concept design, an interactive system provides the designer with the capability of studying and modifying intermediate results. He is thus able to detect and correct errors when they occur, to literally guide the computer toward an optimal solution and to supplement the partially automated design algorithm. The computer thus becomes, not an adjunct to the design process, but a partner in it. The design systems must thus provide for a high level of interaction with the computer. Recognition of the dynamic nature of the various ship design phases and production processes is a prerequisite to effective utilization of the computer. With computing systems and their associated high speed and random access capabilities, the implementation of computer aided design with time-sharing and real time capability has become widespread.

Interfacing techniques other than computer graphics are relatively well developed and, although important, are not considered to need the research and development focus of this study. Computer graphic technology, on the other hand, requires technology improvement, and will thus be considered here in some detail. Computer graphics has been regarded as a major interfacing technique between the CAD/CAM system and the user. It has the potential for high pay-off.

Computer graphics[56,57,58] is especially useful in interactive computing. The great potential of computer graphics results from the combination of the computer with the capability of interaction by and through graphics display. Computer aided design and computer graphics are, in fact, inexorably linked. In a real design situation, there are so many parameters that problem description without the use of pictures is impractical. In design automation, the required rate of information transfer is so high that computer graphics is the only possible medium.

Traditionally, ship design relies very heavily on drawings both for communication and as a means of information storage. The cost of manually preparing, modifying, and storing drawings is high and is increasing rapidly. Drawings to be plotted are often defined and designed by interactive graphics.

The current graphics applications in computer aided ship design and production are elementary. Substantial work needs to be done in this area.

There are many reasons for the underutilization of computer graphics. The following reasons constitute the main ones:

- High graphics hardware cost: Computer graphics equipment is expensive to buy and to use. The storage tube display has emerged as a "low-cost" graphics device and has become popular among many users. However, the drawbacks include slow drawing speeds and inability to erase locally, which precludes dynamic graphics.

  Raster-scan displays were at first expensive and poor in quality. Recent hardware and software advances have improved the performance of raster-scan displays and brought their cost down, so that they can now be used to display good-quality text, line drawings, and shaded and colored pictures. In the future, it can be expected that developments in computer graphics will be in the area of raster-scan technologies.

- High software development cost: Manufacturers have unfortunately placed much more emphasis on the development of hardware than on software, and apparently have rarely tried to make graphics programming easier. The lack of common graphics software and the difficulty of programming displays have played a large part in hindering the use of computer graphics.

  A graphics application program is usually developed for a particular display device, computer system, graphic software, and data management system. The transferability of a graphics program is much more complicated than that of ordinary computer programs. The recent work[59] of ACM SIGGRAPH in standards is improving the definition of functional standards that will specify a software interface between an application program and a graphics package. These efforts should reduce confusion over terminology, lead to more sharable programs, and result in wider understanding and use of computer graphics. A better higher-level, user-oriented graphics language is needed.

- Complex data structure: The problem of data structure is not unique to interactive computer graphics; it is a common problem in all computer applications. Interactive systems in general require data structures more complex than those employed in ordinary programs. The level of complexity of the data structure used in interactive computer graphics requires special consideration. As design systems become more complex, and as the demand for versatility and speed of interactive graphics systems increases, the need for a comprehensive theory of data structure in the engineering design area becomes critical. Other considerations in data structure design include division of labor between local terminals and host computers, networking, and distributed computing.
- Intolerable system response time: System response time is closely related to hardware configuration and the type of data structure used.

The problems of designing a graphical system and integrating it with engineering design and analysis systems are often formidable. Solutions developed must be able to satisfy the needs of the end user at the lowest cost.

6.3 DESIGN AUTOMATION

The objective in designing a computer aided design system is to blend the designers and the computer into a problem solving team able to attain the goals of design and to produce a better product. When attempting to form a system in which designer and computer work together, one should take account of the things each can do better than the other. Designers can create, invent, and judge the merits of different options in solving a problem. A computer can deal with almost unlimited detail, carry out complex calculations accurately and quickly, and hold vast amounts of information. The essence of their relationship is the interactive manner in which the designer can use his experience and judgment to explore ideas and possible solutions to problems and requirements. The design task is allocated between the designer and the computer according to their capabilities. The concepts underlying this allocation depend on the current state of the art in computer science and technology.

Advances in computer science and technology enable more work in design and production to be assumed by computers.

In the present state of computer technology, it is important that the designer be able to interrupt the automated process at the proper moment to supplement existing algorithms which are not entirely adequate. When this is done on-line (with graphical aid), the designer becomes part of the algorithm.

Traditionally, all the decision making is left to the designer, while the computer is asked merely to execute straightforward computations. However, recent progress in computer hardware and software is likely to bring changes to the present situation. Computer hardware is now being transformed by the progress of large scale integrated-circuit (LSI) technology that decreases hardware costs by several orders of magnitude. Furthermore, advances in computer technology in the field of artificial intelligence may radically change our current view of using computers. The large body of concepts and techniques developed in artificial intelligence can be applied to automate a greater part of the design process,[60] freeing the designer to concentrate on those parts of the process in which decisions have a significant impact on the final solution.

Artificial intelligence is the subfield of computer science concerned with the use of computers in tasks that are normally considered to require knowledge, perception, reasoning, learning, understanding, and cognitive abilities. The goal of artificial intelligence is a qualitative expansion of computer capabilities. It has been used both to bring new kinds of resources into the CAD system and to achieve a better working relationship between the designer and the computer.

6.4 PRODUCTION AUTOMATION

The ship production process has been considered complex, heavy, dirty, and dangerous. The parts to be handled are large and heavy regardless of the size of the ship. The working environment is dirty and hazardous due to the presence of rust, paint, oil, and cutting and welding fumes, and the huge steel structures of a ship require many high-above-ground dangerous operations. The environment is noisy and at the mercy of weather conditions. The complexity of the work is evidenced

in the high level of skills required. In addition, a follow-on operation often cannot be defined until prefabricating and assembly conditions are identified, and continuity of the work flow is difficult to maintain with respect to both the working environment and the supply and transfer of parts and materials. These factors not only make standardization of operations difficult, but increase reliance on human experience in making correct judgments on operating methods and procedures. For these reasons automation in ship production has not advanced as far as it has in such other industries as aircraft and automobile production.

In recent years, mechanization and automation of equipment for shipbuilding, particularly in hull production, have made considerable progress, motivated by the demand for rationalization and for savings in labor costs. Advances include automatic stockyard systems, automatic surface treatment from shotblasting to painting, and numerically controlled cutting and welding machines.

However, most of this advanced equipment is far from automatic, as it requires various manual operations. For example, an NC cutter depends on human judgment and operation to control cutting quality through adjustment of cutting speed and flame. Thus most present equipment still relies on the experience of skilled workers.

The flow production approach, in which material flows and workers and machines remain stationary, is one aspect of mechanizing the ship production environment. More work must be done in this area to achieve a greater level of automation.

Given the complexity and size of the ship production process, two approaches[61] to future ship building automation and mechanization can be taken. One involves the use of conventional fixed and large-sized equipment, such as automated piping assembly machines, with more complex mechanisms and computer controls. The other is to develop a machine which is small and self-propelled, and which can perform multifunctional operations. This implies the adoption of robots in shipbuilding, which would release workers from the hazardous working environment. These two approaches, used together, complement each other. In some advanced shipyards, robots have been used in cutting, welding, and fitting materials.

The machines generally called robots vary from automatic machines with a single function to those with artificial intelligence. However, it is difficult to apply industrial robots to shipbuilding in their present stage of development. The work units of ship production are much heavier and larger than in most production work and the environment is complex and difficult to control. As a result, additional capabilities and intelligence are needed in preparing material and in ship assembly. The relatively low investment cost and high potential of robots make them attractive in the automation of ship production, and they could probably be developed to be more economical and workable in the future.

6.5 DISTRIBUTED COMPUTING

Because the cost of hardware is dropping rapidly and because significant advances have been made in mini-computer and micro-processor technologies, the large software systems of today will probably evolve into the distributed systems of tomorrow. Futhermore, since software costs rise slowly each year with inflation, hardware advances should be directed to reducing software implementation and maintenance costs.

The primary reason for distributed processing is to provide a system environment which maximizes information availability. The great appeal of distributed computing is that it offers many of the advantages, and avoids some of the disadvantages, of both the centralized and decentralized approaches. Distributed computing can centralize some functions and decentralize others in the best overall combination for a particular application or organization. The central computer can provide large-scale services that cannot be economically maintained at the local level.

A distributed system has the potential to provide the following advantages:

- Increased efficiency of the central facility due to the transfer to local processors of tasks for which the large machine is not well suited
- Integration of information processing by consolidation of programs and sharing of common data
- Greater user control of and involvement in the distributed functions tied closely to their operations

- Simplification and economy achieved by breaking the system into relatively small distributed subsystems
- Reduced response time for interactive functions performed locally
- Ability to provide required reliability and security by suitable allocation of tasks among distributed subsystems.

There is little doubt that distributed computing will be a primary feature of systems architecture in the future. Successful implementation of a distributed system calls for the development of new technology, especially in the areas of distributed data base management and computer networking.

A number of distributed data base implementations have been reported in the literature[55] in the past year. Many of them are quite large and each has been designed to handle the particular data management needs of a single enterprise. Complementing these implementation efforts in distributed data management is a growing body of research and development for which the major focus is the development of general purpose distributed data systems. For example, a completely generalized distributed data management system would reside on a heterogeneous computer network with different data base systems available at various processors. Communications and data transfer would be possible among any nodes in the network. However, the realization of this goal is still many years in the future.

The basic design of today's computer is still focused largely on mathematical computation rather than on the storing, retrieving, and data organizing functions that computers are primarily being used for. The architecture of computer systems for high-performance, large scale information management is still largely an unsolved problem. As the evolution of information processing continues, there will be an increased *separation* between *computer systems* specialized for reliable, economical storage and processing of large amounts of information (called data base machines), and systems specialized to support traditional numerical computation. Although each local distributed system may have its own local data base, a large shared data base will still be needed for a variety of economic or technical reasons.

The data base machine[62] is a specialized back-end computer which is explicitly aimed at supporting large-scale data bases and providing hardware support for security enforcement, for the storage of the large data base, and for the support of different data base models (relational, network, and hierarchical). Advantages of the data base machine approach include:

- Low processor cost. A low-cost, special purpose minicomputer may perform as well as a high-cost processor optimized for mathematical calculations. Removing the data base software load allows the central processor to be more fruitfully used.
- Shared concurrent access. The data base machine can provide a large centralized integrated data base system for shared concurrent access with security and integration for a large number of on-line users.
- Low storage cost. Pooling the storage requirements of many computers permits the use of more economical high-volume storage devices.
- Compatibility. Interchange of information among such computers has usually been awkward because of incompatibilities between the computers and the data bases. The data base machine concept enables the information to be conveniently shared.

Figure 6 shows an example of the systems configuration in a data base machine environment for an advanced computer aided ship design and production system. This approach uses a minicomputer for distributed computing functions, such as graphical displays, interactive computing, data management, and task execution monitoring. The local processors will possess their own data storage, graphics display, and/or other input/output devices.

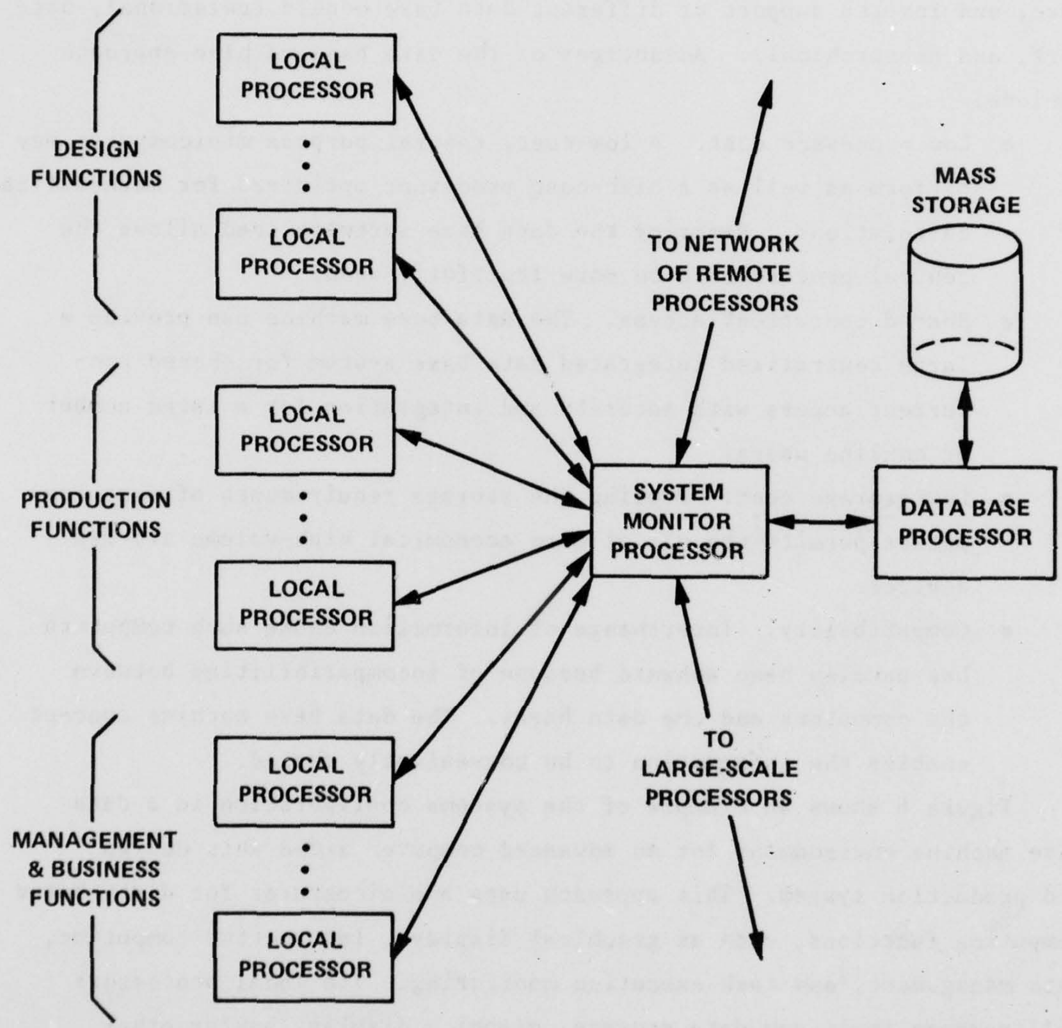
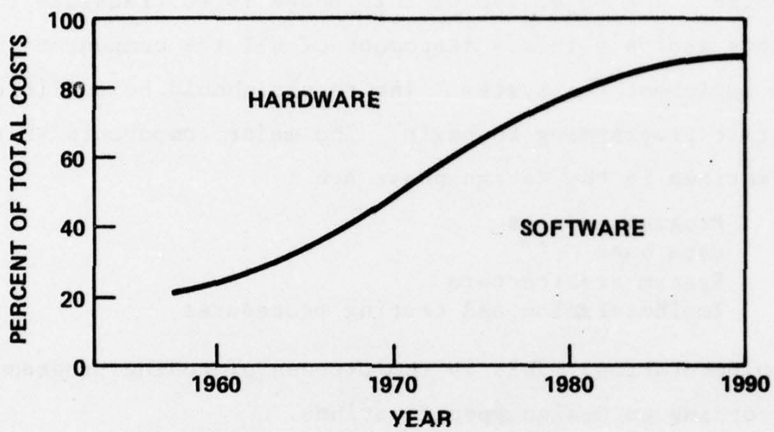


Figure 6 - A Distributed Computing Environment
for Ship Design, Production and Management

6.6 SOFTWARE DEVELOPMENT, ACQUISITION AND MAINTENANCE

The dramatic decline in computer hardware costs in recent years has brought the costs of software development into sharp focus. Compared to the cost of computer hardware, the cost of software is continuing to escalate, as shown in Figure 7.[63]



© From Reference 63.

Figure 7 - Software/Hardware Cost Trends

Figure 7 shows the estimate for software expenditures in the Air Force going to over 90 percent of total ADP system costs by 1985. This trend is probably characteristic of other organizations as well. On one existing system, the World Wide Military Command and Control System, the ratio was roughly 80 percent for software, about $750 million. Since it is unlikely that unit costs for software personnel will decline, methods to increase software productivity and reliability become more and more important. Automated aids and software engineering practices can be developed to increase productivity, to decrease cost, and to improve software reliability. Software engineering is the practical application of scientific knowledge and engineering discipline to the development, operation, and maintenance of computer software systems.

There are two criteria for software systems: correctness and performance. A system is correct if it meets the specification requirements

and is free from design and implementation errors. A system performs satisfactorily if it meets the timing and storage requirements.

There are four major phases in the development of a software system:

- Requirements analysis: This phase involves translation of a user's need into a statement of the functions to be performed by a software/hardware system.
- Design: The objective of this phase is to translate the requirements analysis into a statement of all the components necessary to implement the system. The result should be sufficient to permit programming to begin. The major components which will be described in the design phase are

  Program modules
  Data base
  System architecture
  Implementation and testing procedures

- Implementation: This is the process of coding programming modules according to design specifications.
- Testing: This phase verifies that the coded and other components of the system satisfy the original requirements.

The average cost distribution for development of large military systems[63] was as follows: analysis and design - 34 percent, implementation - 18 percent, and testing - 48 percent, as shown in Figure 8. Current software development practice permits specifications and design errors to remain undetected until testing. Therefore, testing has become the most expensive and unpredictable phase of software development.

In most cases, operational software is not free of error despite the high cost of testing. Residual errors contribute an unexpected cost to the user beyond normal operating and maintenance expenses. Studies[64] indicate that most software errors (80 percent) are introduced during analysis and design. Nothing is as detrimental to successful software development as an incomplete or incorrect requirements analysis specification.

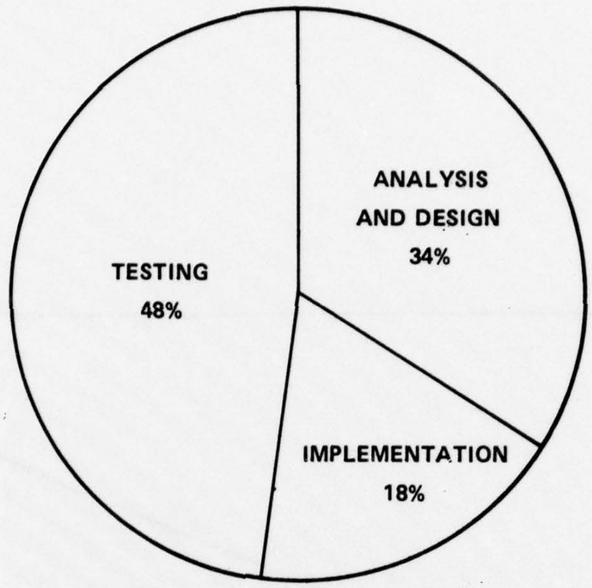
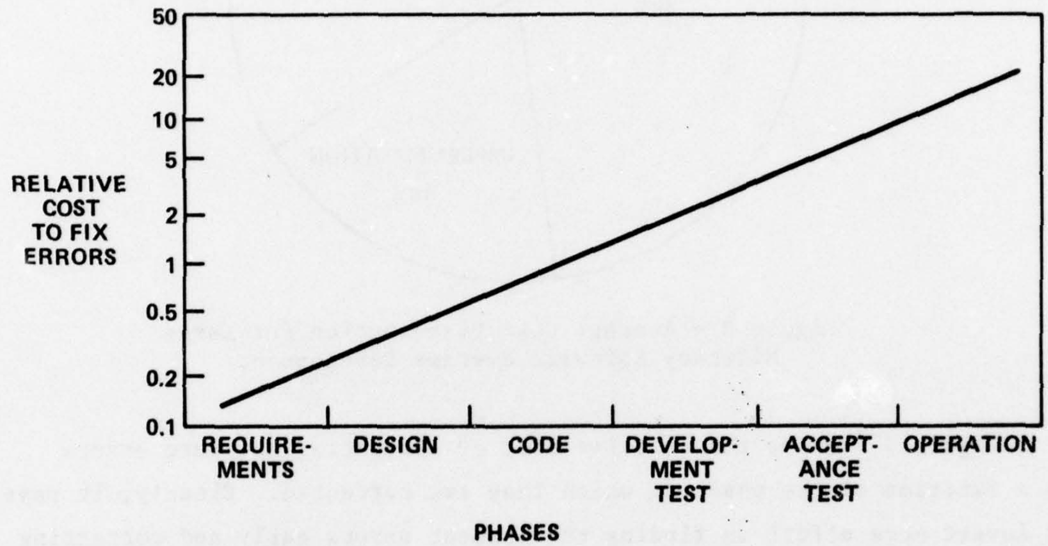


Figure 8 - Average Cost Distribution for Large Military Software Systems Development

Figure 9[64] shows the relative cost of correcting software errors as a function of the phase in which they are corrected. Clearly, it pays to invest more effort in finding requirement errors early and correcting them in one manhour rather than waiting to find them during operation and spending 100 manhours correcting them.

Adoption of a strictly disciplined methodology makes it possible to to reduce significantly the cost of software development and maintenance. A study[65] measured the effects of disciplined programming practices on software development costs for three large software development projects of Boeing Computer Services. The study compared the man-months forecast for the projects by Boeing's traditional estimating procedure with the man-months actually incurred using disciplined programming practices. The average improvement for the three projects when disciplined programming was used was 73 percent over the traditional method.



© From Reference 64.

Figure 9 - Relative Cost of Correcting Errors in Software Development Phases

7. RECOMMENDATION - A 5-YEAR PROGRAM

Chapter 5 describes the goal, requirements, and functions of an advanced computer-aided ship design and production system. It has become apparent that the current computer science technology base is inadequate in some areas and needs adaptation in others to support the design and development of such a system. It is recommended that a five-year program for research and development in the computer science area be initiated to provide the Navy with a computer science and technology base to approach that required by the conceptual system of Chapter 5 and at the same time to provide a congenial and stimulating environment for ship design, production, and repair. In addition, current and projected needs in this area will be met, especially those of the CASDAC project.

The computer science areas covered will include those identified in Chapter 6, i.e.,

- data base design and management
- computer graphics
- design automation
- production automation
- distributed computing
- software acquisition, development, and maintenance

In each of these areas the program will characterize requirements, taking account of the complexity and interdisciplinary nature of the process supported; provide a mechanism for reviewing, exploiting, and influencing ongoing and planned research and development efforts in the rapidly evolving computer science field; put needed results of current research into usable form; and identify and support high pay-off areas needing additional research and development.

The program will help the ships community keep up with and influence technology development so that new developments can more quickly impact current efforts while simultaneously contributing to future planning. The program will make it possible to develop a cadre of research people in the computer science area with a special interest in and knowledge of the needs of the ship design, production, and maintenance community.

The program is considered in two parts. The first relates to program management and technology transfer; the second relates to the technical content of the research and development program itself. Adequate, stable funding is imperative if this program is to realize its potential of making a major contribution in forwarding the Navy's ship design, production, and repair efforts. The funding levels suggested, as shown in Table 1, are modest for a program of the scope we are proposing, especially in view of the magnitude of the effort and its potential impact. However, a considerable research and development effort is already ongoing in the computing science area which this program could exploit. By building on these efforts, a program with the modest funding levels proposed can have a major impact.

7.1 PROGRAM MANAGEMENT AND TECHNOLOGY TRANSFER

The recommended structure for the program management is based on that for several successful research, development, and technology transfer programs including one related to manpower problems, a hydrodynamic research program, and NASTRAN (NASA Structural Analysis) Program. In all instances, the key to the success of the program has been a good program director and an active Advisory Panel. The programs are carried out by both in-house and contractor personnel.

For the program we are recommending, the Program Director will be responsible for

- planning a coordinated research, development, and technology transfer program pursuant to the recommendations of the Advisory Panel
- supervising the in-house portion of the program
- evaluating contract proposals with the participation of the Advisory Panel
- maintaining technical and administrative control of contracts
- maintaining contacts with related efforts in DOD, NASA, and other activities.

An active Advisory Panel will have representatives from the Navy's ship design, construction and repair communities along with the computer science research and development communities.

To assist them there will be a body of consultants from both the industrial and university communities. Panel functions will include

- identifing and prioritizing needs
- suggesting directions for the program
- evaluating proposals, and
- reviewing and critiquing the program

Panel members will keep abreast of developments in the field. They will help to anticipate future needs and identify work to be done, making sure that the program addresses future as well as current needs. The panel's major role will be in advising and assisting the Program Director. It is important that information relating to the Panel's proceedings be sent to those with an interest and a need to know. Proceedings will be open.

The program will address technology transfer issues. Products will be collected, made available, maintained, and further developed as appropriate. Sponsorship of workshops, meetings, newsletters, etc., will help. Also, it is vital that useful products developed as a result of the program are adequately supported with good documentation, technical support, user assistance, training for new users, and a forum for information and experience exchange among users.

We recommend that the Program Director be from ONR and that DTNSRDC be the Navy's lead laboratory in this effort. The Advisory Panel will include representation from the ship design communities of NAVSEC and DTNSRDC, from the shipyard community, and from the computer science communities of DTNSRDC and ONR. The CASDAC Project will be well represented on the Panel. The CASDAC project has already developed interfaces with the shipbuilding industry. These interfaces will also serve this project.

7.2 PROPOSED RESEARCH AND DEVELOPMENT PROGRAM

Current research and development activities in computer science are being sponsored and pursued by many organizations, including many private companies and institutions. DOD, the world's largest computer software purchaser, is engaged in a number of initiatives to improve the cost and quality of Defense software systems. Major Defense-wide initiatives range from a thrust toward common high-order programming languages[66] to the

automation of software development and maintenance processes.[67] NASA, NSF, and other agencies have also supported research through grants and contracts. An outline is presented here of a proposed five-year research and development program in computer science intended to supplement ongoing research and focus on areas which will result in high pay-off or meet special requirements imposed by the computer aided ship design and production systems. This outline is intended to provide the Program Manager and Advisory Panel with initial directions. Flexibility is essential so that advantage can be taken of related developments in the rapidly evolving computer field. Tasks which are being actively sponsored by other agencies or which involve long periods of time and large capital investment, such as automatic code generation or automatic data base design from a problem statement, are not be included at this time. However, developments in those areas will be closely followed and exploited at the appropriate time. Results of related efforts being pursued by other agencies will be evaluated and adopted whenever a significant benefit will result. Cooperative effort with agencies with related problems will be pursued.

Six task areas, which will be needed in support of the development of an advanced computer aided ship design and production system, were identified in Chapter 6 and are outlined here. They include data base management and design, computer graphics, design automation, production automation, distributed computing, and software development, maintenance and acquisition.

For each of these areas, the program will:

- characterize the principal features and requirements taking account of the complexity and interdisciplinary nature of the system
- identify and support high pay-off areas needing additional research and development
- put needed results of current research into usable form
- implement a means whereby products developed can be distributed and maintained.

Task Area I. Data Base Design and Management (See Sections 6.1 & 6.5 of this report)

In spite of the accomplishments in all areas of computer applications including operating systems, interactive systems, and programming languages, there exists no systematic approach to the design of a large complex engineering data base. Data base design continues largely to be an art rather than a science. Much research is underway to alleviate this problem, but additional work is still needed on the design and management of very large, complex engineering data bases for computer aided ship design and production.

The objective in this task area should be to provide technologies and methodologies for the design, management, and utilization of very large data bases, especially in the areas of design representation, consistency maintenance, and security protection under concurrent access and in a multi-user environment. The data base will effectively support applications in various areas which range from engineering applications and graphics design to material inventory control and financial bookkeeping.

Task Area II. Graphics (See Section 6.2 of this report)

Interactive graphics methods provide ship designers with the crucial capability of interaction by and through graphics display. Utilization of graphics technology in Navy ship design is still elementary and highly technology oriented. Procurement problems have made upgrading equipment a nightmare for the CASDAC community. Effective utilization for an application requires a major effort as measured by implementation cost and time. In order to make graphics readily available as a technology for a wide range of applications, generalized and user oriented software interfaces must be developed.

The objective in this area should be to provide technology that will make graphics facilities readily available, in an easy-to-use fashion, to all users for a wide range of applications and at low-cost. In addition, software must be portable and easily implemented.

Task Area III. Design Automation (See Section 6.3 of this report)

The design of the computer aided design system will biend designers and the computer into a problem solving team and allocate the design tasks between the designer and the computer according to their capabilities. Any tasks of the design process that can be efficiently represented by a computer program will be programmed for solving design problems. Traditionally, all the decision making has been left to the designer, while the computer is used merely to execute straightforward computations. Recent progress in computer technology, especially in artificial intelligence, can be used to augment CAD resource capabilities and can provide the CAD system with problem-solving capabilities. Such progress is likely to result in automating a greater part of the design process and so free the designer to concentrate on stages of the design process in which decisions have a greater impact on the final solution.

The objective of this task should be to develop technology so that more of the design process can be automated and more intelligent capabilities included at a justifiable cost.

Task Area IV. Production Automation (See Section 6.4 of this report)

The shipbuilding industry is known to be one of the most labor-intensive industries. In recent years some foreign shipyards have made great advances in mechanization and automation in ship production, but very little R & D work is being directed toward the shipbuilding industry in this country.

From the automation point of view, most present advanced equipment is far from automated, as it requires various hand operations and still relies on the experience of skilled workers. The machines generally called robots vary from automatic machines with a simple function to those with artificial intelligence. The work units of ship production are so heavy and large and the work environment so complex and difficult to control that it is difficult to apply industrial robots to shipbuilding in their present stage of development. Additional capabilities and intelligence must be developed for material preparation and ship assembly and outfit purposes.

The objective of this task should be to identify requirements and develop technology for which high pay-off could result from automation and to encourage the necessary related research and development.

Task Area V. Distributed Computing (See Section 6.4 of this report)

The rapid decline of hardware costs and the advances in minicomputer and micro-processor technologies leave little doubt that the primary systems architecture of the future will involve distributed computing, although the technology is still in its infancy. Current implementations reported in the literature have been designed to handle the particular needs of an enterprise. Complementing these implementations is a growing body of research and development activities in general purpose distributed systems. However, the realization of a complete generalized distributed computing system which will reside on a heterogenous computer network with different data base systems available at various processors is still many years in the future.

The objective of this task should be to identify specific requirements of the computer aided ship design and production system as they relate to a future distributed computing system and to develop the necessary technology to support such a system.

Task Area VI. Software Development Acquisition and Maintenance
(See Sections 5.3.4 and 6.6 of this report)

Early in this decade, a set of programming practices began to appear that seemed to offer a way out of the software difficulties accompanying the development of large systems. Although these new techniques have been widely discussed in the literature, they are not yet widely used. Part of the reason for this lies in the complexity of the techniques and the difficulties management and progammers face in implementing them. The new techniques must be disseminated by means of education and training.

Existing software technology is not adequate to meet current and future needs. DOD, the world's largest software purchaser, has a comprehensive program of coordinated R & D initiatives to improve software engineering tools and methods. Two specific DOD initiatives are to automate significant aspects of software development and maintenance processes

and to increase the availability of software tools throughout DOD.[63] The National Software Works project of DARPA is also an attempt to provide a collection of software engineering and maintenance facilities that can be convienently accessed and shared.

The computer aided ship design and production system, with all the characteristics of large software systems, does not impose specific requirements on its software development and maintenance that are significantly different from other large engineering software systems. However, in view of the many different methods or techniques available or being developed, there is the problem of finding out which ones are most cost-effective for ship design and production purposes. One clear need is to study available new software development techniques and automated tools and to recommend a disciplined systematic approach, from requirements analysis, through design, implementation, testing, and maintenance to software management. A mechanism whereby the tools which have been developed and found useful can be collected, maintained, and made available is needed. The purchaser of software should be provided with a means to specify the task to be performed and to validate that the delivered software is acceptable, interchangeable, and integratable. A training program for all levels of personnel involved in development of the software system for the computer aided ship design and production is needed.

7.3 FUNDING LEVEL

The research and development program proposed does not contain a detailed funding and milestone breakdown. For planning purposes, an annual level of funding (6.1 and 6.2) is recommended. Detailed funding levels and milestones will be developed by the Program Manager and Advisory Panel.

In view of the magnitude of the computer aided ship design and production effort being addressed, the recommended funding level for the proposed research and development effort may seem low. However, as already noted, much related research and development is being pursued in support of other application areas which, it is expected, can be adapted and built upon. An effort of the level proposed will help to ensure that systems developed in the area under discussion become increasingly more capable, reliable, predictable, and cost effective. The return for dollars spent should be many fold.

TABLE 1 - PROPOSED FIVE-YEAR FUNDING

<table>
<tr><th>TASK / FUNDING ($K) / YEAR</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>PROGRAM MANAGEMENT AND TECHNOLOGY TRANSFER</td><td>150</td><td>200</td><td>300</td><td>350</td><td>400</td></tr>
<tr><td>I. DATA BASE</td><td rowspan="6">850</td><td rowspan="6">1,000</td><td rowspan="6">1,200</td><td rowspan="6">1,350</td><td rowspan="6">1,600</td></tr>
<tr><td>II. GRAPHICS</td></tr>
<tr><td>III. DESIGN AUTOMATION</td></tr>
<tr><td>IV. PRODUCTION AUTOMATION</td></tr>
<tr><td>V. DISTRIBUTED COMPUTING AND NETWORKING</td></tr>
<tr><td>VI. SOFTWARE ENGINEERING</td></tr>
<tr><td>TOTAL</td><td>1,000</td><td>1,200</td><td>1,500</td><td>1,700</td><td>2,000</td></tr>
</table>

ACKNOWLEDGMENTS

The authors wish to express their sincere appreciation to all the attendees at the two ONR-sponsored workshops for their interest and participation (See Appendixes B and D). We also extend special thanks to George Uberti and William Freese for their helpful discussions during our visit to the National Steel and Shipbuilding Company.

We also wish to thank the many members of the Computation, Mathematics and Logistics Department of DTNSRDC who have participated in the various discussions which have provided valuable perspectives on the many technical areas included in this report. Special thanks to Tom Corin, Head of the Computer Aided Ship Design and Construction Division, and to Tom Rhodes, Group Leader of the Information Processing Technology Group, for their review of the draft of this report and their many helpful comments and suggestions.

APPENDIX A

AGENDA FOR THE FIRST ONR WORKSHOP

Workshop on Computer Science (current use and future requirements) in support of Ship Design, Production and Repair.

Place: Marriott Key Bridge Hotel, Tel: (202) 524-6400
U.S. 29 & 211, Washington, D.C. 20007

Dates: June 29 & 30, 1977

Host Representative: Marvin Denicoff, ONR
Tel: (202) 692-4564

Workshop Coordinator: Elizabeth Cuthill, DTNSRDC
Tel: (202) 227-1645

June 29, 1977

8:30	Introduction Marvin Denicoff, ONR
9:00	Computer Aided Ship Design and Construction (CASDAC) Tom Corin, DTNSRDC
9:25	Research and Engineering for Automation and Productivity in Shipbuilding (REAPS) Program Jack Williams, IITRI
9:50	Review of Automated Drafting Systems Tom Poltorak, Philadelphia Naval Shipyard
10:10	Coffee Break
10:20	Ship Production and Engineering System (SPADES) Phil Cali, Cali and Associates
10:40	Scheduling Planning and Reporting Data Information System (SPARDIS) William Freese, National Steel and Shipbuilding Co.
11:00	Integrated Program for Aerospace-Vehicle Design (IPAD) Susan Voight, NASA Langley
11:20	Integrated Computer-Aided Manufacturing (ICAM) Donald O'Brien, Air Force Materials Command

	11:40	Some Current Development in Computer-Aided Geometry Design (Film) Richard Reisenfeld, University of Utah
	12:00	Lunch
	1:30	Some Recent Advances in Computer Technology Ivan Sutherland, California Institute of Technology
	1:50	Structural Analysis and Design Technique for Software System Ralph Bravoco, Softech, Inc.
	2:10	Coffee Break
	2:20	Computer Data Bases for Design Charles Eastman, Carnegie-Mellon University
	2:50	Artificial Intelligence Patrick Winston and Berthold Horn, MIT
	3:30	Discussion
	4:00	Closing
June 30, 1977		
	8:30	Review of problems, needs, priorities, and potential solutions; development of program outline to address the needs identified
	12:00	Lunch
	1:30	Discussion
	2:30	Closing

APPENDIX B

ATTENDANCE LIST FOR THE FIRST ONR WORKSHOP

Private Shipyards

Richard Abate	Electric Boat Division
John Eckenrode	Bethlehem Steel Corporation
William Freese	National Steel and Shipbuilding Co.
Patrick Kelley	Newport News Shipbuilding Co.
Christine Mills	Bethlehem Steel Corporation
James Montgomery	Newport News Shipbuilding Co.
Patrick Rourke	Newport News Shipbuilding Co.
George A. Uberti	National Steel and Shipbuilding Co.
Jack Wasserboehr	National Steel and Shipbuilding Co.

Ship Design Agents

Filippo Cali	Cali and Associates
John Gebhardt	CADCOM, Inc.
Cecil B. Shaver	Nickum and Spaulding Associates, Inc.
Laurus E. Sutton	Gibbs and Cox, Inc.

Institutions

Charles M. Eastman	Carnegie-Mellon University
Berthold Horn	Massachusetts Institute of Technololgy
Richard Reisenfeld	University of Utah
Ivan Sutherland	California Institute of Technology
Adries van Dam	Brown University
John C. Williams	IIT Research Institute
Patrick H. Winston	Massachussets Institute of Technology

Others

Ralph R. Bravoco	Softech, Inc.

Other Government Agencies

Donald O'Brien	Air Force Material Command
Bradford Smith	National Bureau of Standards
Susan Voigt	NASA Langley

Navy

Ruey Chen	David W. Taylor Naval Ship R&D Center
C. Michael Chernick	David W. Taylor Naval Ship R&D Center
Tom Corin	David W. Taylor Naval Ship R&D Center
Linwood Culpepper	David W. Taylor Naval Ship R&D Center
Elizabeth Cuthill	David W. Taylor Naval Ship R&D Center
Marvin Denicoff	Office of Naval Research
Arthur Fuller	Naval Ship Engineering Center
Gene Gleissner	David W. Taylor Naval Ship R&D Center
Gordon Goldstein	Office of Naval Research
David K. Jefferson	David W. Taylor Naval Ship R&D Center
Bob Morgan	Naval Sea Systems Command
Raye Parrott	Naval Ship Engineering Center
Tom Poltorak	Philadelphia Naval Shipyard
Thomas Rhodes	David W. Taylor Naval Ship R&D Center
Mark Skall	David W. Taylor Naval Ship R&D Center
Bernard Thomson	David W. Taylor Naval Ship R&D Center
Ken Williams	Naval Sea Systems Command

APPENDIX C

AGENDA FOR THE SECOND ONR WORKSHOP

Workshop on Computer Science Research and development in support of ship design, production and repair.

Place: Marriott Key Bridge Hotel, Tel: (202) 524-6400
U.S. 29 & 211, Washington, D.C. 20007

Date: Nov. 21, 1978, 9:00 a.m. - 4:30 p.m.

Meeting classification: Unclassified

Host Representative: Marvin Denicoff, ONR
Tele: (202) 696-4304

Workshop Coordinator: Elizabeth Cuthill, DTNSRDC
Tele: (202) 227-1645

* * * * * * * * * *

9:00 Introduction
Marvin Denicoff, ONR

9:10 Highlights of June 1977 First ONR Workshop
Elizabeth Cuthill, DTNSRDC

9:30 Shipbuilding Industry Overview
Ruey Chen, DTNSRDC

9:50 Coffee break

10:10 Future Computing Environment Suggested and Computer Sciences Areas Identified for Research & Development
Ruey Chen, DTNSRDC

11:00 A 5-year program - Recommendation
Elizabeth Cuthill, DTNSRDC

11:30 Recommendations for Computer Utilization in Shipbuilding
Richard Riesenfeld, University of Utah

12:00 Lunch

1:30 Discussion

4:30 Closing

APPENDIX D

ATTENDANCE LIST FOR THE SECOND ONR WORKSHOP

<u>Private Shipbuilding Industry</u>

Richard Abate	Electric Boat Division
John Daidola	M. Rosenblatt and Son, Inc.
Tom Doussan	Avondale Shipyards, Inc.
John Gebhardt	CADCOM, Inc.
Erik Hansen	Bath Iron Works
Charles Heller	CADCOM, Inc.
F. W. Helming	ADTECH, Inc.
Ramesh Kakad	Sun Shipbuilding Co.
Maurie Marcus	J. Ray McDermott, Inc.
C. Nelson	Electric Boat Division
T. Swart	J. J. Henry Co.
George Uberti	National Steel and Shipbuilding Co.

<u>Institutions</u>

Steven Fenves	Carnegie-Mellon University
Read Fleming	Brown University
Tomas Lozano-Perez	Massachusetts Institute of Technology
Richard Riesenfeld	University of Utah
Bruce Roberts	Massachusetts Institute of Technology
Abraham Waksman	Temple University
Kevin Weiler	Carnegie-Mellon University
Patrick Winston	Massachusetts Institute of Technology

<u>Other Government Agencies</u>

Manos Castrinakis	Maritime Administration
Roger Lapp	Army Const. Engineering Research Lab.

Navy

Philip Anklowitz	Naval Ship Engineering Center
Sidney Berkowitz	David W. Taylor Naval Ship R&D Center
Jack Brainin	David W. Taylor Naval Ship R&D Center
Abel Camara	David W. Taylor Naval Ship R&D Center
Craig Carlson	David W. Taylor Naval Ship R&D Center
Ruey Chen	David W. Taylor Naval Ship R&D Center
Tom Corin	David W. Taylor Naval Ship R&D Center
Elizabeth Cuthill	David W. Taylor Naval Ship R&D Center
Marvin Denicoff	Office of Naval Research
Chuck Dungford	Puget Sound Naval Shipyard
Al Edwards	Portsmouth Naval Shipyard
Nathan Fuller, Jr.	Naval Ship Engineering Center
Tom Gallagher	Naval Ship Engineering Center
F. J. Garner	David W. Taylor Naval Ship R&D Center
Gene Gleissner	David W. Taylor Naval Ship R&D Center
Leonard Haynes	Office of Naval Research
William Holden	Naval Material Command
Jack Lenard	Long Beach Naval Shipyard
Richard Lutowski	Naval Ship Engineering Center
J. Machado	Naval Electronic Systems Command
Bob Morgan	Naval Sea Systems Command
Ron Munden	Mare Island Naval Shipyard
Tom Poltorak	Philadelphia Naval Shipyard
Thomas Rhodes	David W. Taylor Naval Ship R&D Center
Louis Rosenthal	Naval Sea Systems Command
Lewis Smith	Naval Ship Engineering Center
CDR. Peter Trapgaard	Portsmouth Naval Shipyard

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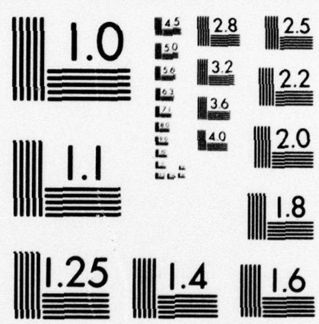

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